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Circular economy is key! Designing a digital artifact to foster smarter household biowaste sorting

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ABSTRACT

Waste volumes are rising. This is a problem, as they worsen environmental challenges such as climate change. At the same time, however, waste bears valuable resources – yet untapped. The concept of a circular economy bears the potential to unleash these resources. In the short run, only changing the waste sorting behavior of citizens can effectively contribute to circular resource flows, as waste management companies cannot ensure the purity of waste by purely technical means. Aligned with the digital realm, this work focuses on designing a digital artifact that contributes to improved household waste sorting. Using a design science research approach, we develop the artifact's design with input from theory, 23 interviews with potential users and practitioners, and evaluate a prototypical instantiation in a large German city. We contribute to literature and theory by generating design knowledge on information systems for improved biowaste and residual waste sorting by individuals. We derive as key design principles the importance of awareness and transparency, social influence, education and confirmation, and incentives. Our solution embracing those principles enhances the awareness of circular economy processes and the relevance of correct waste sorting. At the same time, our solution is relevant to solving waste management companies' current challenges such as the incineration of valuable biowaste as part of residual waste.

1. Introduction

> "How fruitful is the smallest circle if you know how to cultivate it well."
>
> (Johann Wolfgang von Goethe)

There are only seven years left to attain the United Nations' Sustainable Development Goals (SDGs) and address the severe environmental challenges, such as growing mountains of waste. The global annual waste generation was predicted to double by 2050 through population growth and urbanization (Kaza et al., 2018). [1]The concept of circular economy (CE) is seen as a promising concept to address this issue.

By transforming the current linear "*take-make-dispose*" economy into a circular one, CE aims to narrow, slow, and close material loops and decouple economic growth from resource use (Bocken et al., 2016; Ghisellini et al., 2016; Zeiss et al., 2021) However, most global waste today is not recovered but sent to landfills and incineration, leading to a higher demand for resources and energy while magnifying challenges such as climate change or biosphere degradation (Ellen MacArthur Foundation, 2021b, 2021c; Murray et al., 2017). In high-income countries with an established waste management infrastructure, the waste collection rate is almost 100%. Still, large amounts of the waste are incinerated and thus not looped back into the overall resource flow (Kaza et al., 2018). In Germany, for example, 65% of the incinerated residual waste consists of valuable resources such as biowaste, paper,

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[1] German: „Wie fruchtbar ist der kleinste Kreis, wenn man ihn wohl zu pflegen weiß.", Gedichte. Ausgabe letzter Hand. Zahme Xenien VI.

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plastics, and metals. Biowaste has the highest share – almost 40% (Hawlitschek, 2021; German Environment Agency, 2020). In contrast to other waste fractions, biowaste (e.g., inedible food by-products and green waste) cannot be prevented or eliminated. But, if separately collected, biowaste provides the potential to generate valuable products, such as biogas, organic fertilizers, or bioplastics (Fricke et al., 2018; Vea et al., 2018). Especially in times of energy and gas shortages in Europe and other countries, the importance of locally produced biogas as a renewable and independent energy source is obvious.

To foster improved biowaste sorting and subsequent circular resource flows, digitalization and the merits of digital technologies are frequently considered as factors opening up a “window of opportunity” (Aceleanu et al., 2019; Antikainen et al., 2018; Zeiss et al., 2021). However, research on such digital artifacts is still in an early stage. Recent work suggests non-digital feedback systems or gamification approaches to influence individual behavior and improve household waste sorting as a starting point (Lim et al., 2021; Soma et al., 2020; Soomro et al., 2022; Hoffmann and Pfeiffer, 2021). However, scholars call for more empirical and experimental studies to investigate how digital applications can improve the quality of waste sorting, especially biowaste sorting in households (González-Briones et al., 2020; Pedersen and Manhice, 2020; van der Werff and Lee, 2021). While Information Systems (IS) research could provide valuable contributions to this matter, the IS discipline has thus far only sparsely contributed to CE (Hawlitschek, 2023). In particular, IS research has fallen short in investigating its potential to enable citizens’ awareness, empowerment, and responsibility (Zeiss et al., 2021) as a basis for improved biowaste quality. This is particularly important as the incineration of incorrectly sorted biowaste as residual waste further fuels the climate crisis. To meet the SDGs by 2030, simple but effective solutions are required to help individuals change their behavior now. With this study, we thus aim to add an IS perspective on the issue of changing household biowaste sorting behavior by addressing the citizens. Our research question reads: ***How to design an information system that contributes to improved biowaste sorting in households, promoting the urban circular economy?***

We develop design knowledge for an information system that promotes household waste sorting based on theory and 23 interviews. To do this, we apply a design science research (DSR) approach by following the methodological guidelines of Peffers et al. (2007) and Gregor et al. (2020). We evaluate the resulting digital design artifact via a prototypical instantiation in the German city of Frankfurt am Main.

Overall, our findings foster the transition towards a CE. In particular, our design knowledge of IS for improved waste sorting qualifies as Type II theory (theory for explanation), according to Gregor (2006). Our digital artifact helps individuals to correctly sort their biowaste from their residual waste by, among others, illustrating the relevance of proper waste sorting and explaining CE. This design knowledge provides guidance to practitioners (e.g., waste management companies, communal enterprises, and cities) on how to improve household waste sorting and offers a way to harness the potential of digitalization for (business) operations.

2. Theoretical background

2.1. Circular economy

CE aims to narrow, slow, and close material loops and to decouple economic growth from resource use (e.g., Bocken et al., 2016; Ellen MacArthur Foundation, 2013; Zeiss et al., 2021) Instead of following the linear take-make-waste approach, CE aims to reach economic prosperity while minimizing resource input (Zeiss et al., 2021; Bocken et al., 2016; Kirchherr et al., 2017; Geissdoerfer et al., 2017). In our work, we refer to the CE definition by the Ellen MacArthur Foundation (2021a), which defines CE as a systems solution framework driven by design based on three principles: 1) eliminate waste and pollution, 2) circulate products and materials (at their highest value), and 3) regenerate nature.

Within a CE, a technical and biological cycle aim to close resource flows (McDonough and Braungart, 2009). The technical cycle comprises aspects like reusing or recycling metal or plastics (Ellen MacArthur Foundation, 2019). In our work, we focus on the biological cycle and the promising circular potential of biowaste in particular. Biodegradability is a crucial aspect of the biological cycle, as biodegradable materials, e.g., biowaste, can be returned without threatening the ecosystem (contrary to other types of waste material such as plastic or electronic waste) (Geisendorf and Pietrulla, 2018; Bocken et al., 2016). Anaerobic digestion as a method for biowaste treatment has gained wide attention due to the production of valuable secondary products such as biogas and organic fertilizers or compost (Angouria-Tsorochidou et al., 2021). Thus, Biowaste recycling has the potential to regenerate the environment, e.g., by providing fertile soils. To leverage these benefits, biowaste must be sorted appropriately.

For waste management companies in cities with a high population density, the biological cycle of biowaste is also particularly interesting. In contrast to other waste fractions, biowaste cannot be eliminated or prevented – yet it can provide valuable secondary products (Cecchi and Cavinato, 2019). Furthermore, improperly sorted biowaste increases the wet ingredients in the residual waste and thus impairs incineration (Schüch et al., 2016) and increases costs. To leverage the economic opportunities and the potential of correctly sorted biowaste, waste management organizations generally have two options: First, to improve the technical means of waste sorting by investing in advanced sorting plants, or second, to improve waste sorting on its origin. Given the cost and complexity of technical solutions for waste sorting, improving the behavior of human beings – that is, active public participation in waste management by citizens (Knickmeyer, 2020) – is critical.

2.2. Theory of planned behavior and the potential of IS for waste sorting

The motivation of citizens for careful waste sorting depends on various factors, such as social influence, education, awareness, information, incentives, knowledge, convenience, and trust and policy approaches (e.g., Zhang and Zhu, 2020; Pedersen and Manhice, 2020; Li et al., 2020; Panagiotopoulou et al., 2021).

The theory of planned behavior (TPB) of Ajzen (1991) is a well-established theoretical framework to understand and predict individual behavior or behavioral change. It has been applied in a variety of contexts (e.g., Hawlitschek et al., 2018) and allows the subsumption of different types of motivational factors. According to the TPB, the intention, that is, the motivational factors on how hard to try to perform a specific behavior, can be predicted based on three determinants: 1) attitude – the favorable or unfavorable appraisal of a behavior, 2) subjective norm – perceived social pressure to perform a behavior, and 3) perceived behavior control – perception of how easy or difficult a behavior is to perform. Intention and perceived behavior control form the actual behavior. Current literature suggests that the TPB is well suited to explain waste sorting behavior (Yu et al., 2018). Thus we use it to inform our design knowledge for IS that support waste sorting.

IS can be a powerful tool to support behavioral change (Zeiss et al., 2021; Zhang and Zhu, 2020). Embedded sensors, data, and real-time analysis can encourage environmental awareness and promote waste-aware behavior (Esmaeilian et al., 2018). Mobile applications can inform citizens how to sort waste more accurately or provide information on the emptying dates of containers (Bonino et al. (2016) and Rasmussen et al. (2020)). Furthermore, gamification and feedback mechanisms could encourage citizens’ participation in recycling and reduce the overall amount of waste (González-Briones et al., 2020; van der Werff and Lee, 2021).

While the existing literature reports on these examples and use cases, it currently does not provide explicit design knowledge and guidelines regarding the potential of IS to motivate citizens and change their waste sorting behavior (Esmaeilian et al., 2018; Zeiss et al., 2021).

3. Research approach

We base our research on a DSR approach (Peffers et al., 2007), as depicted in Fig. 1. After identifying inadequate sorting of biowaste at the household level as a key problem (step 1), we analyzed the literature and conducted expert interviews to define solution objectives (step 2). In 13 semi-structured interviews with experts and potential users, we developed design principles (DPs) (step 3). Based on these, we demonstrated and evaluated our solution via a prototype in the German city of Frankfurt am Main, conducting 10 additional interviews with experts and (potential) users (steps 4 and 5). As a means of communication, we composed the article at hand and distributed our results via non-academic channels.

DSR focuses on creating new and innovative artifacts as suitable solutions to relevant problems (Hevner et al., 2004; Peffers et al., 2007). Using DSR, we aim for theory for design and action (Gregor, 2006), focusing on "how to do something" (Gregor and Jones, 2007). Specifically, our goal is to develop an innovative artifact that addresses the problem of insufficient household waste sorting. DSR research results in prescriptive knowledge. Evaluating this prescriptive knowledge yields descriptive knowledge with a truth-like value (Sonnenberg and vom Brocke, 2012). As part of the evaluation process, we stick to the evaluation criteria postulated by March and Smith (1995): effectiveness, efficiency, and impact on the user and environment.

4. Development of design knowledge

Based on theory and practice, we develop design knowledge. From a theory point of view, we draw on the TPB (Ajzen (1991). We conducted 13 semi-structured interviews. Our sample of interview partners comprised five waste management experts (WasManExp), citizens as potential users (Us), two international experts in gameful and playful digital artifact design (DesExp), two green IS designers (GrISDes), and one nudging expert (NudgExp). Some subjects served for developing the design knowledge and later for evaluating it (see section 6). We incorporated and covered different overarching areas with the semi-structured interview protocols based on Myers and Newman (2007). The interview protocol comprised four areas: an introduction, a specific question regarding the requirements of the digital artifact, a specific question on data necessary and collected, and a closing. See Table B1 for an excerpt of the semi-structured interview protocol. We recruited our initial participants for the interviews via the personal networks of the authors and continued via snowball sampling: Experts recommended other experts. Although this produced a non-representative sample, it is a well-established research method that provides access to interview partners who may otherwise prove difficult to find or reach (Heckathorn, 1997). Individual interviews lasted from 32 to 102 min (11.15 h in total) and took place virtually. The interviewees resided in Europe (mainly Germany) and Canada, and the interviews were conducted in German or English. We recorded and transcribed each interview via Microsoft Teams, with subsequent manual editing (and eventually translation). In the first step, we investigated the interview data to develop design objectives (DOs). Such objectives concretize the solution space for current problems that the artifact addresses. In the second step, we derived the DPs. DPs specify how to reach the DOs. Table 1 provides an overview of all actors involved in the interviews for the development and evaluation of the design knowledge.

Table 1
Overview of actors involved in the interviews.

Actor	Abbreviation
Waste management experts	WasManExp
Potential users	Us
Experts in gameful and playful digital artifact design	DesExp
Green IS designers	GrISDes
Nudging expert	NudgExp
Actual users	ActUs
Potential users	Us
City representative with a focus on sustainability issues	SusCityExp
Behavioral expert for cognitive psychology	BehavExp

4.1. Design objectives

Our research objective is to develop design knowledge for an artifact that promotes biowaste sorting in urban households. Based on the current challenges and expectations mentioned in the semi-structured interviews by waste management experts (detailed in the following), we derived three DOs:

1) The artifact leads to higher separately collected biowaste quantities.
2) The artifact promotes users' understanding of the circular economy.
3) The artifact raises users' awareness of the importance of biowaste quality.

First of all, the artifact is meant to increase separately collected biowaste quantities to increase the quality of residual waste. WasManExp2 points out that "*there is still much potential in sorting […]. The proportion of biogenic fraction in the residual waste is quite high. I think our biggest problem is the quantity of biowaste [in residual waste].*" Biowaste burned together with residual waste reduces the overall calorific value, as WasManExp5 explains. So, more waste is needed to reach calorific thresholds. On the contrary, better biowaste sorting would lead to a higher calorific value and, in turn, yield higher production rates of biogas as renewable energy. WasManExp1 emphasizes, "*if you extrapolate today if every plant worked optimally, you could already replace quite a bit of natural gas.*"

Second, the artifact is meant to clarify users' understanding of the CE. This means, above all, citizens must understand the potential of closing the biological cycle. WasManExp2 highlights "*that things are actually kept in the cycle […] [help us to become] more self-sufficient,*" pointing to the current dependency of many European countries on foreign natural gas. Citizens need to understand "*waste as a raw material*" (WasManExp2). Digital technologies can improve understanding as "*[waste management companies can use them to enhance] communicating with customers and get closer to them*" (WasManExp3). Therefore, making waste sorting and the circular economy more understandable is our artifact's second objective.

Third, the artifact is meant to raise users' awareness of the importance of biowaste quality. Currently, bioplastic products like toothbrushes or waste bags end up in the biowaste, even if they are not naturally biodegradable (WasManExp4). Thus, they stay in the compost

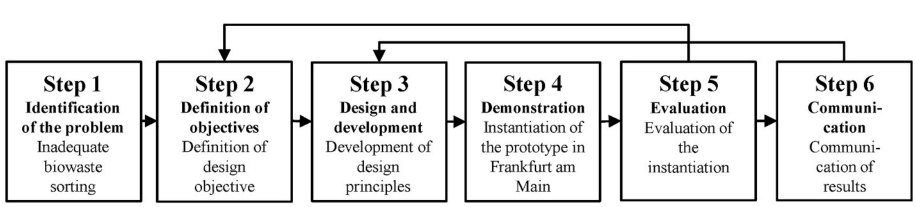

Fig. 1. Our design science research process (based on Peffers et al. (2007)).

and reduce the quality of the secondary products, and may even add to the accumulation of microplastic in the environment (Colombini et al., 2022) WasManExp4 explains: "*It is still plastic.*" The European Union, which sees itself as a global leader in waste management, makes a biowaste container obligatory from 2023 on (European Commission 5/22/2018). Thus, strategies are needed to reduce the interfering materials in biowaste in the future. WasManExp1 expects "*reductions in interfering materials*" from the artifact. As this is, according to WasManExp2, an "*attitude problem*," and we do not have the option to control the biowaste quality technically, we aim to increase the awareness of the importance of biowaste quality with our artifact in the third DO.

4.2. Design principles

The DPs are derived from the interviews and structured alongside the TPB as an informing theory. We derived the DPs by clustering the wishes, expectations, and statements mentioned in the interviews with the potential users, gamification and nudging experts, and IS designers. Table 2 summarizes these DPs and structures them alongside the established DP dimensions of Gregor et al. (2020). In the following, we detail how the DPs were derived from the interviews, are reflected in existing literature, and how they can be matched with the TPB.

4.2.1. Principle of Awareness and Transparency

The Principle of Awareness and Transparency should promote the users' favorable appraisal of waste sorting behavior. While awareness accounts for the individual environmental knowledge and thus understanding of environmental problems, transparency is necessary to show individuals how their actions positively impact the environment. Nearly all interviewees mentioned that increasing awareness about the impact of their waste sorting is necessary for promoting the respective waste sorting behavior. Table 3 displays exemplary illustrative interview quotes.

Not only our interviewees but also research points to the importance of awareness for waste sorting behavior: Understanding and seeing the positive impact or negative consequences of their own actions transparently can motivate people to start or continue waste sorting. Scholars agree that citizens' environmental knowledge and awareness could positively impact environmental behavior, e.g., waste sorting. (Rasmussen et al., 2020; Lim et al., 2021; Soomro et al., 2022). However, there are gaps between environmental knowledge and behavior (Chen et al., 2021). Transparency could increase trust in the waste management system. Also, our interviewees mentioned a lack of transparency regarding waste sorting and management processes, which is reinforced by regionally different sorting and disposal systems. Often, the waste collectors are not the waste disposers; they sell the waste to other companies without making it transparent for citizens where it finally ends up. If waste management processes are more transparent for citizens, trust in the subjects in waste management processes can increase (Chen et al., 2021). Households are more likely to sort waste if they believe in the effectiveness of the local waste disposal structures (Zhang and Zhu, 2020).

A few studies have investigated awareness and transparency for changing waste sorting behavior and associated it with the TPB (Soomro

Table 3
Exemplary interview quotes for the principle of awareness and transparency.

Design Principle	Interview Quotes
Awareness and Transparency	• "I think that many people do not know [what happens with the waste] because I have only recently learned about it myself. […] I did not realize, for example, that 100% of the residual waste is actually incinerated." (Us2) •"We have to make it visible to people what they are doing. […] You need to see their influence immediately in some way. […] We always have the discussion that they say 'Yes, I, what can I change?'" (WasManExp2) •"No, I honestly do not know it myself in detail. […], somehow you do not know what happens afterward, and I think that would also be a very important aspect […] to carry the awareness, this knowledge somehow into the broad masses" (Us3) •"You know, make it simplified but make it more in terms of what's relatable to them, more meaningful for them. […] That [.] is then motivation because I can see an impact on this." (DesExp1) •"Say think again […] because it means the energy that's still in that biowaste can be used elsewhere" (GrISDes1) •"How much energy you could actually get out of it […] is exciting" (GrISDes2)

Table 2
Design principles, their dimensions as proposed by Gregor et al. (2020), and the relationship to the Theory of Planned Behaviour.

Design Principle	Aim (DO), Implementer, User	Application Context	Mechanism	Rationale	Relation to the TPB
Awareness and Transparency	To promote the user's favorable appraisal of the waste sorting behavior (DO.1; DO.2; DO.3)	Regional waste management systems in developed countries Adaption based on the regional systems	Provide transparent information about waste management processes and the positive impact of each user	Transparent information and awareness allow users to understand and trust the positive impacts of waste sorting and can increase the favorable appraisal of waste sorting behavior	Attitude toward the behavior
Social Influence	To increase the user's perceived social pressure to sort their waste through descriptive and injunctive norms (DO.1)	Monitoring and displaying the waste of individual households	Monitor and display the quantities of separately collected biowaste, compare it to neighbors or the average, and show that others of approving waste sorting	Social influence shows users if others sort waste by themselves or approve of waste sorting behavior leading to perceived social pressure	Subjective norm
Education	To promote the user's perception that waste sorting is easy to perform (DO.1; DO.2; DO.3)	Agreement of households that their data is shown Regional waste management systems in developed countries	Provide information about correct waste sorting and waste reduction	Education on correctly sorting and reducing waste can strengthen user's control beliefs that one possesses resources and fewer obstacles to waste sorting	Perceived behavior control
Confirmation and Incentive	To change the user's behavior, control beliefs, and influence future waste sorting intentions positively (DO.1)	Adaption based on the regional systems Monitoring and displaying the waste of individual households	Monitor and display the quantities of separately collected biowaste, show the progress of the user, and provide incentives for good waste sorting behavior	Feedback can strengthen the user's control beliefs by recognizing that they have control over their outcome. Incentives can foster the user's behavioral beliefs that waste sorting leads to a desirable outcome for themselves.	Feedback effects

et al., 2022; Zhang et al., 2015). We follow Zhang et al. (2015) in assuming that transparency and awareness influence the attitude that links waste sorting behavior to a positive outcome and form a higher favorable appraisal of waste sorting. Creating awareness by transparently showing the impact can foster the attitude that waste sorting is good, valuable, and responsible. The rationale for the DPs thus follows: *Transparent information and awareness allow users to understand and trust the positive impacts of waste sorting and can increase the favorable appraisal of waste sorting behavior.* Therefore, our artifact shall provide transparent information about waste management processes and show their positive personal impact on each user.

4.2.2. Principle of Social Influence

The Principle of Social Influence aims to increase the users' perceived social pressure to sort their waste through social influence. Our interview partners especially mentioned their interest in social comparisons, so providing feedback about their performance compared to others (see Table 4).

Research indicates that social influence effectively encourages behavior change (Abrahamse and Steg, 2013; Grilli and Curtis, 2021). According to the TPB, social norms can be descriptive and injunctive. A social comparison could reinforce descriptive social norms, that is the extent to which one perceives that others sort waste, and creates perceived social pressure to sort waste (Helmefalk and Rosenlund, 2020; van der Werff and Lee, 2021). However, social comparison could lead to unintended boomerang effects, as DesExp1 and NudgExp emphasize. If a person in a household is already good at waste sorting and sees that others perform worse, they may tend to care less about their behavior and think that it is already good enough (van der Werff and Lee, 2021; Abrahamse and Steg, 2013). Research indicates that injunctive norms, so showing that it is good to sort better than other persons or focus on competition and cooperation, could reduce the boomerang effect (van der Werff and Lee, 2021). The subjective norm of the TPB (Ajzen, 1991) means the perceived social pressure to perform a behavior. As research suggests that social influence forms social pressure, we consider our Principle of Social Influence as an antecedent of subjective norms. Our rationale follows: *Social influence resulting from the perception that other users sort waste or approve of waste sorting behavior leads to perceived social pressure*. Our artifact should therefore monitor the sorted waste, compare it to similar households, and show that others approve of the behavior.

Table 4
Exemplary interview quotes for the principle of social influence.

Design Principle	Interview Quotes
Social Influence	•"That's [social comparison] definitely a very effective way to do it. […] Competition works really well when there is actually something to compete for." (DesExp1) •"There is, of course, the question, with whom exactly actually is compared. So that this is important or meaningful information. Is it the neighbor or someone comparable?" (Us3) •"It's a question of presentation: If a leader board or other scoring board emerges from this […], then I could imagine this is exciting, and I have a certain incentive." (GrISDes1) •"Hm, to put the whole thing in relation would be, of course, still exciting […] again, feedback like am I there now somehow above average or below." (GrISDes2) •"Or social comparison. […] That you can see where you stand and then compare it to your neighbors'. […] but if you're very, very frugal and then you see that the others consume a lot, then you tend to consume more because you think yes, well. In the other direction, if you're one of the high consumers and then you see that the others are restrained and doing well, then I should do that too." (NudgExp) •"We [humanity] have become successful through social cooperation and competition." (DesExp2)

4.2.3. Principle of Education

The Principle of Education aims to enhance the knowledge of users on how to sort their waste. Research and our interview partners consider education an important approach to fostering waste sorting behavior (see Table 5).

Research shows that not knowing how to sort waste correctly is one factor that prohibits waste sorting (Sheau-Ting et al., 2016; Pedersen and Manhice, 2020; Bonino et al., 2016). Similarly, Rasmussen et al. (2020) see a lack of information instead of a lack of motivation as a significant barrier. According to research and our interviewees, focusing on education about waste sorting is an effective way to improve waste sorting behavior (Zhang and Zhu, 2020).

Perceived behavior control of the TPB is the perception of the ease or difficulty of performing a behavior. Education on how to sort waste correctly could influence the control beliefs of households, hence the belief that people possess the resources and have fewer obstacles to executing a certain behavior (Soomro et al., 2022; van der Werff and Lee, 2021; Sheau-Ting et al., 2016). Therefore, we suggest that education is an antecedent of perceived behavior control. Our rationale follows: *Education on correctly sorting and reducing waste can strengthen users' control beliefs that one possesses resources and fewer obstacles to waste sorting.* Hence, our artifact should provide useful and easily understandable information about waste sorting and reduction.

4.2.4. Principle of Confirmation and Incentive

The Principle of Confirmation and Incentive aims to change the user's behavioral, normative, and control beliefs and influence future intentions regarding waste sorting through feedback and incentives is the aim of our Principle of Confirmation and Incentive. It consists of two parts feedback and incentive.

Our interviewees especially mention their wish to get feedback about their waste sorting behavior (see Table 6). Furthermore, they wished for a feedback function to display and passively track their behavior. Feedback is proven effective for pro-environmental behavior (van der Werff and Lee, 2021; Helmefalk and Rosenlund, 2020; Sheau-Ting et al., 2016). As people usually do not reflect on their behavior, getting feedback via the artifact can make it more visible and easier to reflect on (Lim et al., 2021).

Building upon the feedback, interviewees request an incentive (see Table 6). Previous research has shown that incentives foster pro-environmental behavior and waste sorting (e.g., Helmefalk and Rosenlund, 2020; Sheau-Ting et al., 2016; Zhou et al., 2021). Feedback and

Table 5
Exemplary interview quotes for the principle of education.

Design Principle	Interview Quotes
Education	•"I think it is a matter of education. […] because let's say 30- to 70-year-olds grew up in total capitalism, where the idea of environmental protection only came in late, and separating waste and so on is actually a newer idea now, and most people do not recognize it." (Us1) •"One function, for example […] could be an education thing, so this goes in the one trash, this goes in the other, or I can select what I have right now, and the application shows me where it goes." (Us2) •"I think it is super important if tips like that, i.e., information on waste sorting, are played in from time to time, or if there's more information about the individual waste garbage cans when you click on them." (NudgExp) •"And then also a clear picture of how the garbage should be sorted concretely in the community. […] a kind of function, where I enter something, and they tell me exactly that you do not put it in the yellow bag, but you put it in the residual waste, because it is hard plastic, for example." (GrISDes1) •"Composting, recycling, all these things do take much time and effort to think about. And I think that is where digital solutions […] would help with that aspect of taking a lot of the guesswork away; I would focus more on the educational side of it. (DesExp1)

Table 6
Exemplary interview quotes for the principle of confirmation and incentive.

Design Principle	Interview Quotes
Confirmation and Incentive	•"When you say you have the possibility to weigh garbage […] if you can determine these deltas, I personally would find it extremely exciting to get my garbage amount averaged [in the application]." (GrISDes1) •"The only thing I want from the app is that it tells me I've had a sense of achievement." (DesExp2) •"If you, as a community, manage to reduce your residual waste within the next six months, [the waste management company] will donate a box of beer." (Us2) •"If you are targeting adults, you need things that are a bit more tangible, and you know, a bit more real-world kind of thing. […] monetary incentives, things like that." (DesExp1) •"But at first, it would undoubtedly be exciting […] to get clarity. How much waste is actually generated? I think that would be an incentive to reduce waste. Definitely." (Us3) •"I then ask myself a bit of the question, what's in for me then? […] If I got a monetary benefit right away, that would be more likely. It does not have to be a benefit in the sense that your garbage becomes cheaper. Benefit also means for me the biodegradable pencil in the ten-pack" (GrISDes1)

personalized incentives are highly cost-effective for behavior change, as digital solutions enable them easily (Tong et al., 2018).

Feedback and the associated incentives are not directly linked to the determinants of intentions of the TPB but can be integrated as feedback effects. Ajzen (2020) describes that the performance of behavior results in information about the actual outcomes, reactions, and facilitating factors. This feedback about the actual behavior can change the behavioral, normative, and control beliefs and influence future behavioral intention. Feedback about individual performance could enhance self-efficacy, that is the control beliefs of individuals (Abrahamse and Steg, 2013; van der Werff and Lee, 2021). We conclude that feedback impacts perceived behavior control. Otherwise, incentives foster the behavioral belief that waste sorting leads to the desired outcome of an incentive and reinforces positive attitudes (Zhang and Zhu, 2020). Our rationale follows: Feedback can strengthen the user's control beliefs by recognizing that they have control over their outcome. Incentives can foster the user's behavioral beliefs that waste sorting leads to a desirable outcome for themselves. Our artifact should have features for providing feedback and include an incentive based on individual behavior.

5. Instantiation of the design knowledge in a field study

We instantiated our developed design knowledge through a field study in the German city of Frankfurt am Main. In this section, we first underline the role of Frankfurt am Main as a suitable test environment for our digital artifact. Second, we describe the study setup, procedure, and detailed design decisions for our digital artifact "TrennMonitor" (in English: "SortingMonitor").

5.1. Frankfurt am main as a pilot area for smarter household waste sorting

Frankfurt am Main is the fifth biggest city in Germany, with a population of over 750,000 citizens in 2022 (Office of Statistics and Elections of the City of Frankfurt am Main, 2022). It is a suitable place for our field study for three significant reasons:

First, the city is continually growing in citizens, implying an increase in households and waste (Hawlitschek, 2021). However, the city's waste sorting rate for biowaste is low, as 40% of the residual waste consists of biowaste (FES Frankfurter Entsorgungs- und Service GmbH, 2022). "*There is still much potential in terms of sorting,*" says WasManExp2, who knows the waste sorting situation in Frankfurt am Main. Further, WasManExp1 emphasizes that due to insufficient sorting, the biowaste treatment plant "*is not the biggest biowaste disposal plant in Frankfurt, but the waste incineration plant.*" The low amount of separately collected biowaste leads to less bioenergy and higher costs as residual waste has the most expensive disposal in Frankfurt am Main (Environmental Office of the City of Frankfurt am Main, 2021). Improving biowaste sorting in Frankfurt am Main will significantly increase bioenergy and decrease the costs for the city and the citizens.

Second, Frankfurt am Main is eager to transit to a zero-waste and smart city. The city committed itself to becoming a zero-waste city and aims at an official certification of Zero Waste Europe, a non-governmental organization that helps cities and municipalities prevent waste generation and promote separate collection and recycling. The goal of the zero-waste strategy in Frankfurt am Main is to reduce the residual waste per capita and year from 205 to 120 kg (265 lbs) until 2035. Moreover, Frankfurt aims to reduce the whole municipal waste annually by 2% per capita (Environmental Office of the City of Frankfurt am Main, 2021). Recently the city signed the Circular City Declaration and is now part of a European initiative of cities promoting the CE (Wilfer, 2022; Environmental Office of the City of Frankfurt am Main, 2021). Moreover, Frankfurt am Main has a digitalization strategy that includes smart waste management and aims to become a smart city (City of Frankfurt am Main, 2021).

Third, the local waste management company of the city, the *FES Frankfurter Entsorgungs-und Service GmbH*, is transitioning from a waste management company to a resource management company. The company is actively involved in the further processing of the waste and can profit from the benefits. Regarding the biowaste, the subsidiary company *Rhein-Main Biokompost GmbH* handles the city's waste in its composting and anaerobic digestion facilities. The bioenergy, as well as the compost, is locally used in Frankfurt am Main. Thus, the facilities, and the expertise to transit to a circular city for biowaste, already exist in Frankfurt am Main. In the course of multiple research and innovation activities (e.g., Gimpel et al., 2021; Hoffmann et al., 2021), *FES* has installed a dedicated pilot weighing system for waste containers in one of the waste trucks, which facilitates the measurement of waste generation data on a household level for personal feedback. As depicted in Fig. 2 below, the weight of the respective waste container is captured during the emptying process based on an RFID chip with a unique identifier and a pilot retrofit weighing system. The data is transferred to a cloud-based system via a telematic unit.

In conclusion, Frankfurt am Main is a suitable city to prototype our artifact due to the high potential for better biowaste sorting, the fulfillment of the prerequisite of a supporting and interested waste management company, and its goals to become a zero-waste and smart city.

5.2. Field study procedure and design decisions

Following agile development principles, we developed a prototype of the "SortingMonitor" application. The prototype was continuously

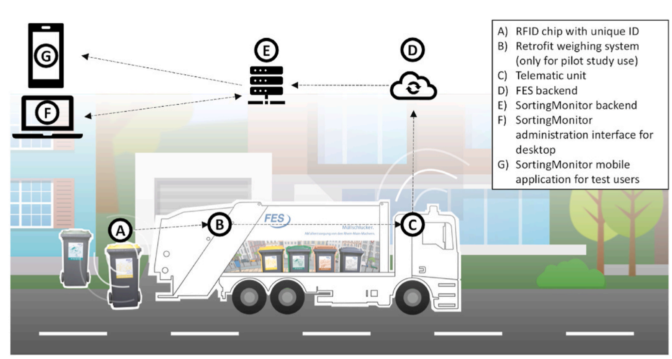

Fig. 2. IS architecture of the artifact; source: FES

revised and adapted before and during the field study based on interviews conducted and feedback collected. Exemplary adaptions of the prototype during the agile development process were inserting the individual average in the reports on the weight of the waste, modifying the colors of the bars and replacing the biowaste and residual waste icons. In agreement with the Frankfurt environmental office, we selected a suitable city district as a pilot area for our field study. In June 2022, we contacted 100 households (jointly covered by one tour of an FES waste truck) via mail, informing them about the possibility of participating in a study on waste sorting behavior. This yielded seven participating households. Note that we deliberately selected single-family houses to facilitate a direct and precise mapping of weighing data to households.

After a virtual informational event, the seven households decided to participate in the study. The required waste weighing data to populate our artifact was transferred from the FES backend to a dedicated “SortingMonitor” backend, which was further processed for administrative and visualization purposes (see Fig. 2). In the following, we provide a detailed overview of the design decisions and user interface design of the “SortingMonitor“ prototype.

5.2.1. Welcome Page and privacy agreement

The Welcome Page presents the name of the artifact, *“SortingMonitor,” the* logo, the mascot, “*Fessie*” of *FES,* a brief overview of the various functions, and contact options. The further use of the application requires an agreement to the terms and conditions of use and the privacy statement (see Fig. 3).

5.2.2. Proportion of biowaste

On the first page, captured in Fig. 4, the users see details on their biowaste production and get information on other users’ average biowaste production. On the one hand, this feedback should increase control beliefs so that users can control their waste behavior, contributing to perceived behavior control (*Principle of Confirmation and Incentive*). On the other hand, comparing oneself to the other participants should create perceived social pressure and the will to score better than other participants, strengthening the descriptive social norm (*Principle of Social Influence*).

5.2.3. Rating

Users’ biowaste sorting behavior is categorized as “*Improvement needed,” “Good,”* or *“Super,”* as shown in Fig. 5. These categories and accompanying pictures and messages should approach the injunctive social norms (*Principle of Social Influence*).

5.2.4. Waste generation compared to City’s average and the City’s goal for waste production

Fig. 6 presents the total amount of a user’s waste compared with the average waste quantities in the city and the goal of an ideal sorting divided into biowaste and residual waste. The bars adapt based on the collections. As the number of household members differs, the user can adjust it individually via a dropdown menu. The illustration combines the descriptive social norms via the comparison with the city average and the injunctive social norms via the comparison with a goal. It focuses on cooperative thinking by creating an identity of being a citizen of Frankfurt am Main and by having the common goal of better sorting and reducing waste (*Principle of Social Influence*).

5.2.5. Analysis

The *Analysis* shows in detail the weight of the collected waste containers for residual waste and biowaste based on the collection date (see Figure A1). Moreover, three indicators are shown: the overall waste weight, the change of waste weight regarding the last collection, and the overall average of all collections of one user. Providing detailed feedback should increase the users’ control beliefs for influencing their waste generation. Comparing the quantities over time should result in perceived ease of waste sorting and reduction. This pays for the *Principle of Confirmation and Incentive,* as the illustration should contribute to perceived behavior control.

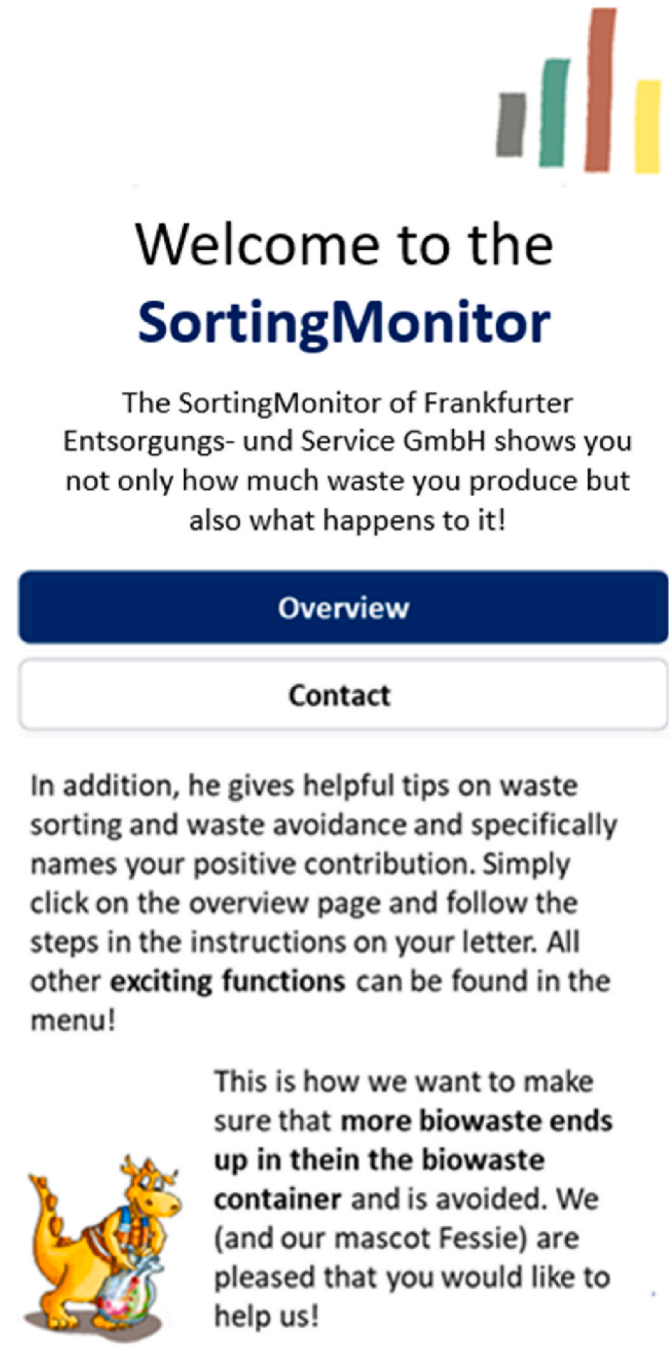

Fig. 3. Representation of the welcome page; source: FES “SortingMonitor“

5.2.6. Tangible impact

To raise awareness and transparency of waste management processes, we allow households to compare their waste production to the average production in Frankfurt as well as to the target production (see Fig. 6). By weighing and summing up the biowaste of each household, we help them to analyze how much compost and biomethane they could have generated (see Figure A2). Due to adding tangible conversions, we also allow them to see their potential CO_2 emission avoidance. Providing such elevated transparency based on individual numbers should increase trust and customer satisfaction in waste management processes. Moreover, it should influence the behavioral beliefs that link waste

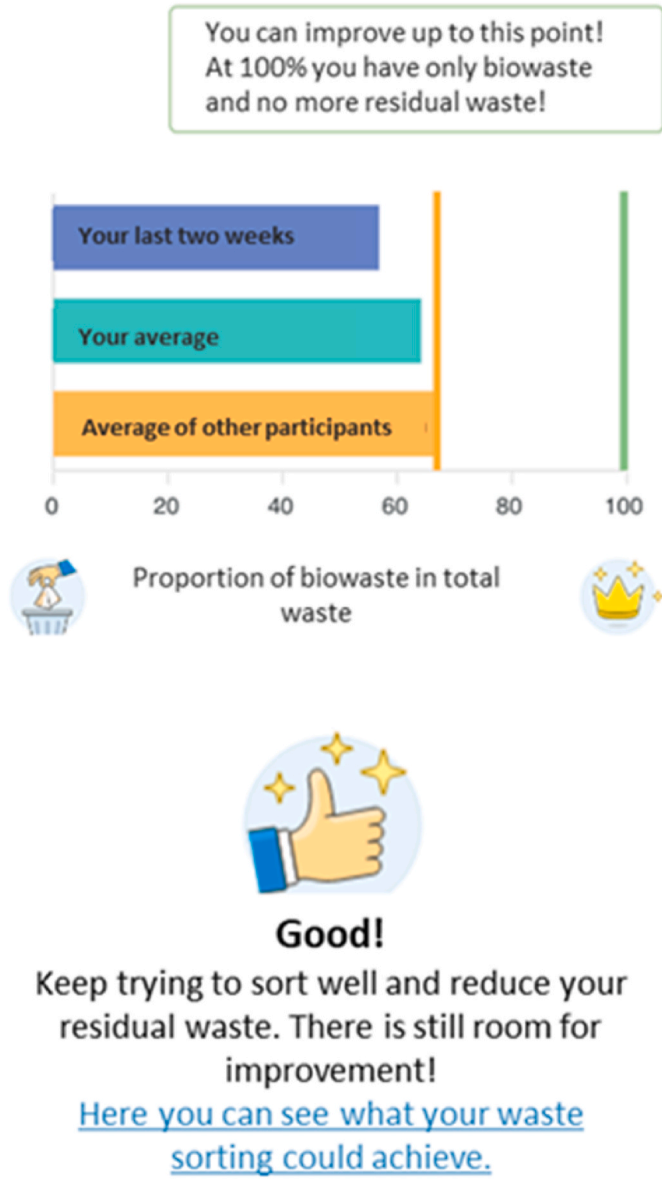

Fig. 4. Representation of the proportion of biowaste in total waste; source: FES "SortingMonitor"

sorting behavior to a positive outcome. As such, it should form a higher favorable appraisal of biowaste sorting. Hence a positive attitude toward its effects is conveyed (*Principle of Awareness and Transparency*).

5.2.7. Incentive

The offer of an incentive should promote a favorable appraisal of the behavior of households. It should also strengthen the belief that one's own waste sorting has positive effects on one's person (*Principle of Confirmation and Incentive*). This is implemented by a progress bar (see Figure A3). Each week, the user gets points based on personal behavior and performance in relation to the other participants. Based on points, the user moves closer to a voucher for compost (incentive) that was, among others, produced by its own biowaste.

5.2.8. Tips and information

Lastly, the page *Tips and Information* links to three websites for further information (see Figure A4), such as a website elaborating on the difficulties of plastic in biowaste. Users can also search for different types of waste and how they should be disposed of. The tips should facilitate waste sorting by educating the users. The idea is to strengthen the control beliefs and increase the perceived ease of waste sorting (*Principle of Education*).

6. Evaluation, expansion, and transferability of our results

The following sections describe the evaluation of the design knowledge and expansion based on interviews with actual users, potential users, and experts. We use the well-established evaluation criteria of effectiveness, efficiency, and impact on the environment and users to evaluate the prototype (March and Smith, 1995).

Within a period of eight weeks, the participants in our field study received real-time data on their household waste. During this time, 46 collections were recorded, with an overall biowaste quantity of 416 kg (917 lbs) and an overall residual waste quantity of 148 kg (326 lbs). After this period, we asked the participants to fill out a short online survey and invited them for 30 min interview slots. Four participants responded to the survey, and two of them agreed to participate in the interviews. Since the quantitative results of our pilot study are impacted by the limited time, seasonality effects, and the number of participants, we additionally conducted qualitative interviews to strengthen our assessment. The additional qualitative interviews were carried out with the two actual and further potential users and experts. We based the semi-structured interview protocols on Myers and Newman (2007). The focus was on assessing our artifact's effectiveness.

Overall, we conducted ten evaluation interviews. To get immediate feedback about the prototype and to justify the underlying theory, we interviewed two actual users (ActUs1 and ActUs2), six potential users (Us3, Us4, Us5, Us6, Us7, and Us8), and two experts, namely a city representative with a focus on sustainability issues (SusCityExp), and a behavioral expert for cognitive psychology (BehavExp). Potential users are living in single households in Frankfurt. We recruited them via personal networks and social media. Since potential users and experts (in contrast to our actual users) had no direct access to the personal feedback mechanisms of the "SortingMonitor" application, we guided them through the different functions of the application (represented by screenshots). We asked them for feedback based on the evaluation criteria. The two actual users participated in the eight-week study and thus had detailed knowledge about the different functions of the application. Therefore, the interviews with actual users started straight with the second step. Some feedback, e.g., regarding smaller display errors, was immediately implemented in the prototype.

6.1. Evaluation of the design knowledge

Given our field study design, we qualitatively evaluated whether our artifact achieves our DOs.

> DO.1: *The artifact leads to higher separately collected biowaste quantities.*

During various interviews, we gained the impression that users perceived the potential of the "SortingMonitor" application to influence their waste sorting behavior positively. To sum up, users' opinion of the application is positive regarding quantities of collected biowaste. For instance, Us7 states, "*I think it definitely leads to higher biowaste quantities.*" and Us3-Us6 think the artifact will improve their intention to sort waste better, implying higher biowaste quantities. Us3 believes: "*that the sorting behavior can improve when you see, ok, I am not doing as well as maybe others or as desired yet.*" ActUs2 confirms the impression of Us3 in stating that "*what triggers the desire to use the application? So to see what I can create in my garden in terms of biowaste over the year.*" ActUs2 was surprised and learned "*what belongs in the biowaste container […] I had learned a few things that can be put in there, for example […] the tea bags, which we hadn't put in there before.*" ActUs1 and ActUs2 had the feeling that during the pilot phase, they disposed of more biowaste in the

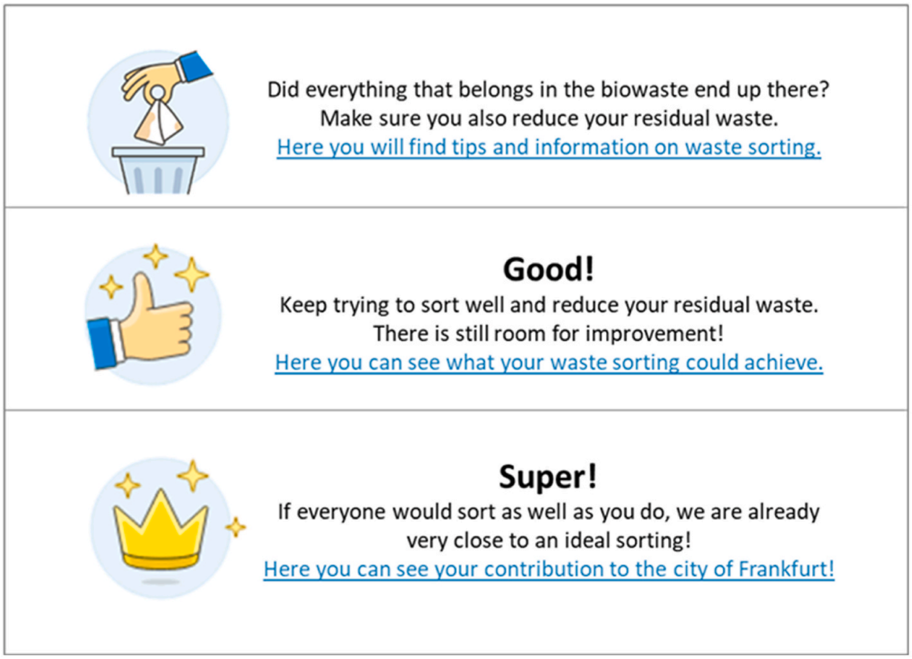

Fig. 5. Representation of the different rating categories; source: FES "SortingMonitor".

biowaste container instead of the residual waste container. The artifact has the potential to lead to higher separately collected biowaste quantities by increasing the intention of performing waste sorting behavior (DO.1). However, due to the short period of our field study, we can only rely on qualitative interview statements instead of a comprehensive quantitative analysis.

DO.2: *The artifact promotes users' understanding of the circular economy.*

In general, the users' feedback shows that the artifact promotes the understanding of a circular economy. For instance, Us7 thinks, "*it certainly contributes to the fact that one takes the topic of waste sorting and the circular economy more seriously because one deals with the topic actively and consciously.*" Also, Us6 would agree that the artifact reaches this objective. For Us3, "*awareness is almost the most important point, so that I understand what happens with the waste, […] and that this has a positive impact on the environment*". ActUs1 says it shows "*the positive – what it [waste sorting] leads to.*" ActUs1 and ActUs2 stated that the application helped them understand CE better. BehavExp thinks it "*increases the understanding of the common good in the first place.*" Thus, the prototype fulfills our second DO.

DO.3: *The artifact raises users' awareness of the importance of biowaste quality.*

Summing up, the users' feedback shows that the artifact raises the awareness of biowaste quality. For instance, Us6 states, "*By thinking about your waste behavior, you generally think more about the do's and don'ts of waste sorting.*" The application motivates ActUs1 to "*sort thoroughly […] and reduce the residual waste*". ActUs1 and ActUs2 are convinced that the application's use has led to a higher awareness of biowaste quality.

Second, to assess the efficiency of the artifact, we consider its use of resources. The prototype is fully automatic, so no manual intervention is necessary during runtime. Nevertheless, the prototype needs server capacity and access to the internet, which consumes energy. As it is based on weighing sensors and RFID chips in every container, the artifact is most efficient when this infrastructure is already available, like in our pilot field study in Frankfurt am Main. Our artifact consumes resources primarily through the initial investment in infrastructure and the energy consumed by the server. Therefore, the added value of recovering materials should be compared quantitatively with the resource consumption of the artifact itself.

Third, we evaluate if the impact on the environment of the artifact is positive or negative. We argue that the prototype positively influences waste sorting, leading to higher quantities of biowaste, biogas, and compost and fewer emissions due to a more efficient incineration process of residual waste. During the short pilot period of eight weeks, the seven participating households produced about 245 kWh of biomethane and 220 kg (485 lbs) of compost. Biogas, as a renewable energy source, saves CO_2 emissions and reduces the dependency on fossil resources from other countries. Creating compost within the city increases the potential of local food production and avoids the loss of nutrients. Further, the increased awareness and understanding of the CE could lead to more thoughtful and sustainable user decisions regarding material cycles. The artifact provides the user a better experience and control of their waste generation. Seeing their personal impact could lead to the feeling that they contribute with their behavior to critical environmental problems in their respective city.

To sum up, we designed an artifact that contributes to improved biowaste sorting, promotes the urban CE, and shows that the developed design knowledge is practically viable. Table 7 shows the summary of the evaluation of the prototype.

6.2. Expansion of the design knowledge

While the evaluation confirms that the instantiated design knowledge contributes to fulfilling the DOs, we recognized further development options within evaluation interviews and the literature. Merging those insights, we suggest three expansion possibilities for smart waste management applications in cities, namely measuring biowaste quality, including multi-family houses, and enhancement of the acceptance and usage of the artifact. In the following, the expansion possibilities are explained in detail:

6.2.1. Measuring biowaste quality

In the future, the artifact should include more information and tips

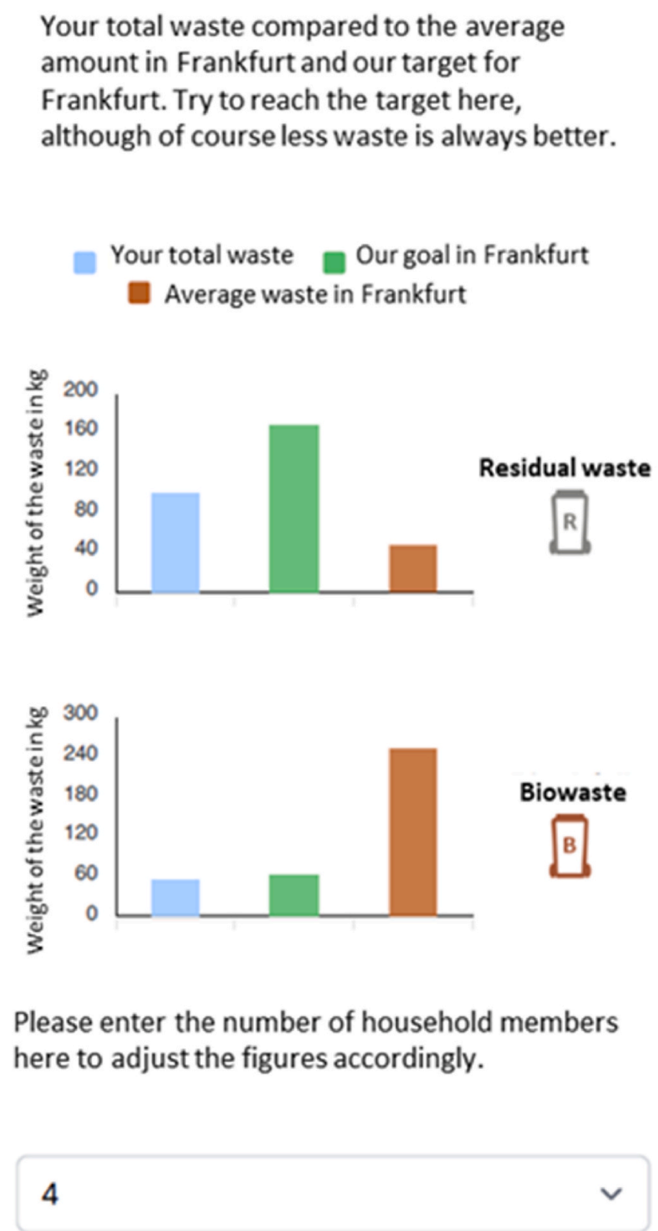

Fig. 6. Representation of the comparision with the cities average; source: FES "SortingMonitor".

Table 7
Evaluation of the prototype (based on March and Smith (1995)).

Criteria	Objectives	Evaluation
Effectiveness (regarding DOs)	Higher biowaste quantities	(✓)
	A better understanding of CE	✓
	Higher awareness of biowaste quality	✓
Efficiency	Low use of resources	(✓)
Impact on the environment and the user	Positive environmental impact (through higher quantities of biowaste) and better users' understanding of CE	✓
	Positive impact on interested users through getting feedback about waste generation, seeing the personal contribution to solving environmental challenges and getting compost.	✓

about the correct biowaste quality and, if possible, a quality measurement. For the quality measurement and detection of misplaced waste, several technical possibilities exist. Sensors and artificial intelligence can detect metal, glass, or plastics in the biowaste when the container is emptied (WasManExp1, WasManExp5). Another option is to offer individual waste sorting consulting based on manual sorting analysis. Such services could be booked via the artifact and delivered face-to-face to individual households for a more powerful effect (Abrahamse and Steg, 2013).

6.2.2. Including multi-family houses

The artifact is currently based on weighing the waste containers of single-family households. However, Popova and Sproge (2021) suggest that single-family households have, per se, a higher positive attitude towards waste sorting than multi-family houses. Thus, it is essential to consider ways to integrate multi-family houses. Our interviewees propose competition with other multi-family houses. Us4 even thinks it could be "*a blatant motivator if [..] they [families that live together in a house] do that together.*" For SusCityExp, it would also be possible to "*compete with other apartment buildings theoretically.*" BehavExp believes that the "*identification would be reduced […] You would have to strengthen the trust that others are pulling together in the same direction.*" Group feedback could convey a group norm with which persons want to conform due to group pressure, according to Abrahamse and Steg (2013). Thus, the future artifact should be compatible to be used in multi-family houses and develop strategies to increase trust and convince the households to use it.

6.2.3. Approaches to enhance the acceptance and usage of the artifact

First, the analysis should be more competitive and comprehensible. The interviewees wished for more goals to compare in the artifact if one is already on a good path. Additionally, the feedback should be less analytical but easier to understand, e.g., by including messages or symbols and pictures based on the behavior, as is currently the case in the final rating. According to our interviewees, our artifact currently addresses users with an analytical mindset. Therefore, other target groups could be addressed by changing the design of the functionalities. A future artifact could have a selection between different views at the beginning, leading to a different design based on other target groups.

Second, the incentive structure could be adapted (e.g., to monetary units or value vouchers). A few interviewees mentioned that composting would not be a real incentive for them, but they wish for a more monetary one, like offsetting the waste fees (Us7). SusCityExp says, "*if the waste* fees *would be related,*" the interest in the incentive and the whole "SortingMonitor" would be higher. Third, the artifact should be more interactive and target-group related. The interviewees wished for a waste sorting game, search per picture, or scanning barcodes. BehavExp emphasizes the importance of addressing the target group, which DesExp1 and DesExp2 emphasized. The expert thinks the artifact currently points to people who have a fundamental interest in waste sorting and the environment. There is no one-size-fits-all approach, but the future design could address more or other target groups effectively.

6.3. Transferability of the results

Since the design knowledge is generalized and based on the well-known TPB, it can easily be transferred to other waste fractions. The following aspects need to be considered: Change in the artifacts aim, application to different target groups, cities, and waste fraction specialties. On the one hand, within the CE, the primary goal is to minimize waste, and then the lower-level goal is to collect the waste separately. Therefore, a change in the artifact's aim to reduce waste is possible (e.g., by getting incentives if less waste is produced). On the other hand, the artifact could be applied to other cities if the following aspects are considered: First, adaptation to regional sorting and collecting rules. Second, different functions or designs may be necessary based on culture and country. Third, the infrastructure must be available, e.g., RFID chips in the waste containers, the waste truck's weighing sensors, and the automatic transfer to digital data storage. Fourth, the waste management company not only collects but also processes the waste, or cooperation with the buyer of the waste is necessary to make it possible to increase transparency and awareness. Once the infrastructure is available, the local problems and target groups are identified, and information collected, the highest effort would be the respective redesign of the frontend of the artifact and the connection to the infrastructure. Afterward, it could be operated with low effort.

7. Discussion

The paper presents design knowledge for a digital artifact that improves household waste sorting and promotes urban CE. Using a DSR approach, we defined the DOs of the artifact and proposed more specific DPs. We prototypically instantiated the in Frankfurt am Main and evaluated the artifact's effectiveness, efficiency, and impact.

7.1. Implications for research and theory

The work contributes to research in three areas: 1) by providing nascent design theory and instantiating a prototype, 2) by contextualizing the TPB in the area of IS changing waste sorting behavior, and 3) by extending the sparse IS literature in the domain of CE.

First, we provide DPs as nascent design theory and a prototypical instantiation based on the design knowledge and propose expansions for further development of instantiations of the artifact. Gregor and Hevner (2013) distinguish between three types of DSR artifacts contributions: Level 1 contributions cover specific instantiations such as products and processes. More abstract level 2 contributions aim at nascent design theories such as DPs, constructs, or methods. The most abstract and mature level 3 contributions refer to well-developed design theories. Our research contributes to the first two levels. We first develop nascent design theory (level 2) in the form of DOs, related DPs, and specific design guidelines. The evaluation of this design knowledge by way of a prototypical instantiation equals a level 1 contribution.

Second, our DPs are theoretically backed, and we contextualize the TPB within the domain of waste sorting. By identifying antecedents for the elements of the TPB, we show how IS can improve individual waste sorting behavior. Current research mainly focuses on which element of the TPB is most influential regarding waste sorting or extends the TPB through additional elements (e.g., Ma et al., 2018; Wang et al., 2021). We follow Zhang et al. (2015), who state that more attention must be given to identifying factors influencing the TPB elements regarding waste sorting behavior. Building on this, we identify and theorize the relationship between our DPs as influential antecedents and the elements of the TBP.

Third, we contribute to IS literature within the domain of CE. We show how IS can leverage its potential to enable individual awareness, empowerment, and responsibility and shift individual behavior towards CE. By spreading the artifact through the local waste management company, a shift of cities or beyond can be induced in the future. In doing so, we contribute to the research objectives of Zeiss et al. (2021) by addressing and extending *enacting circular material flows with IS.*

7.2. Practical implications

This work makes a significant contribution to practitioners such as waste management companies, communal enterprises, and cities in two ways: 1) By addressing a real-world problem of communal enterprises, and 2) by promoting the urban transition towards CE.

First, our artifact addresses the need for waste management companies to identify ways to improve household waste sorting, especially for biowaste. In this vein, our design knowledge was informed by the practitioner's insights and expectations. Further, existing digital solutions proposed by prior research are at an early conceptual stage. In this regard, our work extends and improves the recent contributions (e.g., Bonino et al., 2016; Rasmussen et al., 2020) by presenting design knowledge and building upon existing behavioral theories. By countering the high amount of currently wrong-sorted waste, our artifact provides the potential to leverage economic benefits for the waste management company and environmental benefits for the cities. We instantiate our prototype in a real-world setting in the German city of Frankfurt am Main. By showing the procedure, describing our implementation in detail, and providing information about possible expansions, our work can guide further improved real-world piloting or field studies. In this regard, we improve the knowledge about IS-based solutions for changing waste sorting behavior and the current early-stage solutions.

Second, our research assists the transition toward a CE in cities. By improving the waste sorting and the separate collection of biowaste, our work provides a step towards more CE in cities and a functioning local biological cycle by presenting the example of the German city of Frankfurt am Main. As the biogas and the compost, both generated from the city's biowaste, are locally used for the city's energy supply, landscaping, and local food production, the city creates its own biological cycle on the macro level. Moreover, fostering citizens' understanding of this local cycle can improve their engagement in biowaste sorting and CE on the micro-level. Finally, in times of climate and energy crisis and war, every additional self-sufficient source of gas increases the security of supply.

7.3. Limitations and future research

This work has limitations. First, we build our design knowledge upon a literature review and interviews. Including more research from more disciplines and interviewing additional experts or potential users might alter our results. In this vein, we developed the design knowledge, and the prototype, especially for the pilot district in Frankfurt am Main, which limits the generalizability of the results. Future research could develop more abstract and mature design knowledge as a level 3 contribution. Second, due to temporal and technical constraints, we could not implement all aspects our interviewees wished for or the literature recommends. Thus, we propose that future research could expand and improve the artifact as outlined in section 6.2 above. Third, our field study with the prototypical instantiation is limited by the number of participants, their potential self-selection bias, and any bias potentially caused by the social attention to this topic. Furthermore, technical restrictions and the short run time limit the results of our instantiation. The piloting would have to run over several months or even years to gauge any long-term impacts. Future research should build on our work to understand how factors such as convenience influence sustainable behavior change. Fourth, due to the practical constraints that resulted from evaluating our artifact based on a pilot study in the field, our current observations and data analysis are limited to a qualitative approach. Thus, we propose that future research complements our work with a large-scale and long-term study that facilitates a quantitative assessment of behavior changes.

8. Conclusion

CE is one promising strategy to aid urban stakeholders in times of the climate and energy crisis and growing waste volumes. Biowaste has the potential to be transformed into biogas as an additional source of renewable energy, but only if the waste sorting quality is right. So activities to improve waste sorting quality must start where the waste is susceptible: Urban households. By using IS as a tool to foster behavior change, we investigate how to design an artifact that promotes household biowaste sorting and urban CE. In line with this design knowledge, we developed a prototype, instantiated it in the German city of Frankfurt am Main, and evaluated its effectiveness, efficiency, and impact. Based on the evaluation interviews, we present clear paths for future developments. We contribute to research and practice by generating design knowledge and proposing how to address waste management companies' current waste sorting challenges.

CRediT authorship contribution statement

Carlotta Crome: Investigation, Writing – original draft, Writing – review & editing, Methodology. **Valerie Graf-Drasch:** Supervision, Writing – original draft, Writing – review & editing. **Florian Hawlitschek:** Supervision, Conceptualization, Writing – original draft, Writing – review & editing. **Daniela Zinsbacher:** Investigation, Conceptualization, Writing – original draft, Writing – review & editing, Methodology, Project administration.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Florian Hawlitschek reports financial support was provided by FES Frankfurter Entsorgungs-und Service GmbH. Florian Hawlitschek reports a relationship with FES Frankfurter Entsorgungs-und Service GmbH that includes: employment.

Data availability

The data that has been used is confidential.

Acknowledgement

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Appendix A

Fig. A.1. Page Waste Analysis per Collection Date; Source: FES "SortingMonitor"

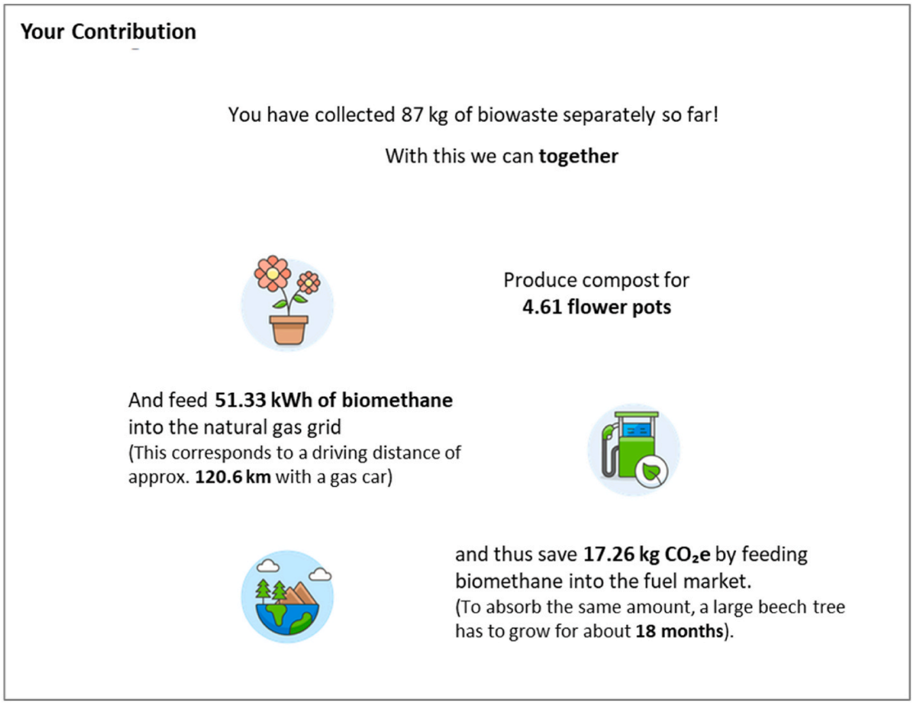

Fig. A.2. Page impact of the collected biowaste; source: FES “SortingMonitor“

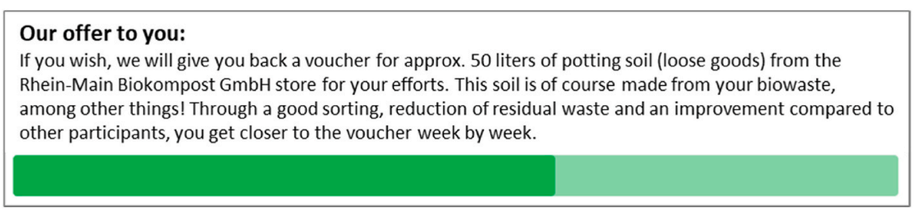

Fig. A.3. Page compost voucher as incentive; source: FES “SortingMonitor”

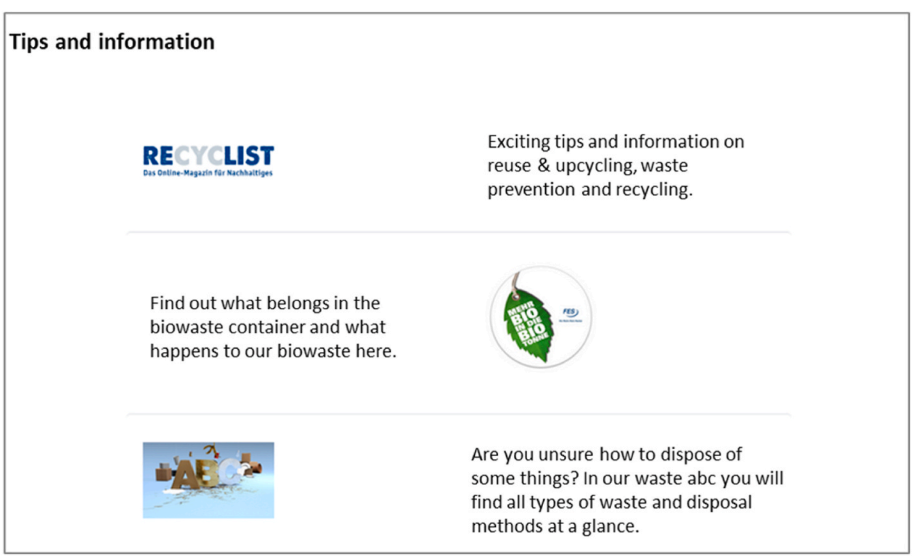

Fig. A.4. Page tips and information; source: FES “SortingMonitor“

Appendix B

Table B.1
Excerpt of the semi-structured interview protocol to develop design objectives and principles

Section	Questions
Opening	•In your estimation, what happens to the waste in a perfect world? How do you rate the current waste sorting? • What do you think is going well, what is going badly?
Area of Expertise	Detailed questions regarding the area of expertise, for example: **WasManExp:** •How does the (bio)waste get to the plant and how is it processed afterward? •What happens to the end products, the compost and the biogas? •Is it possible to say across the board how much bio-waste, how much biogas and correspondingly how much heat can be generated? **Us:** •Do you already use applications that give you feedback on your behavior (e.g., fitness tracker, voice learning app, etc.)? •What appeals to you about them? What functions make you use them? •Would you find a digital application that could reflect your waste production exciting, and would you use it? **DesExp:** •What do you think are the good gamification elements to improve waste sorting? •Which features could you imagine for a digital application for waste sorting? **GrISDes:** •Which functions of a digital application can you imagine for waste sorting? •In your opinion, what should be considered when designing the digital application? **NudgExp:** •What do you think are the best nudging tools that could help with waste sorting? •How could these be implemented in a digital application? •What obstacles/challenges do you see in using these nudging mechanisms?
Digital Application and Data	•What potential do you see in the increasingly better availability of data in a wide variety of areas (like energy or waste)? •What data is necessary for such an application? •In your experience, which data do people give out without hesitation? Which not? •What other data could enhance such a digital application? •What obstacles and challenges do you see in using such an app?
Closing	•Could you imagine using the app? •What would be important for you personally to use the digital application? •What would you like to see in the future for waste management and waste sorting in your city?

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