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Less is more: Encouraging Surplus Food Consumption through an integrated Mobile Application

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Abstract: This paper proposes an intervention using personal Information and Communication Technologies (ICTs) to help consumers reduce household food waste. Across the global food-supply chain, about one third of all edible food is lost or wasted each year, and this issue is particularly pressing in in the global north. We present a detailed overview of consumer activity in relation to household food waste using the Multilayered Installation Design Approach (MID). We trace consumer activity along the acquisition, storage, consumption, and disposal stages and provide a comprehensive set of recommendations on how to use personal ICTs to reduce household food waste rooted in the extant empirical literature. We then develop a concept for an application that integrates the full suite of potential avenues for intervention in one place.

Keywords: Food Sharing; Food Waste; Installation Theory; Mobile Application; MID; Surplus Food

1. Introduction

Across the global food-supply chain approximately 1.3 billion tons of food are lost or wasted each year. This is equivalent to one third of all edible food being disposed of across all stages from production to consumption [1]. In the global south, the majority of food loss occurs on the production side due to a lack of efficient agricultural technology and limited infrastructure [2]. In Western Europe and the US, however, the majority of food is wasted at the consumer level [1]. In fact, across countries in the European Union, households are the single largest contributor to food waste with over 50% of overall food waste originating there; an average of 92 kg per capita per year [3]. This enormous waste of food commonly raises concerns on environmental, social, and economic levels. With the UN setting the aim to halve food waste and loss by 2030 as part of the Sustainable Development Goals [4], this not only raises concerns over the impacts of food waste, but over the very feasibility of reaching such a vital goal. This paper will therefore focus specifically on food waste in developed countries, and more precisely on optimization of matching supply and demand in the last segment of the food chain, the consumer.

There are significant challenges to solving the issue of household food waste in Europe, given that drivers of food waste are both conscious and unconscious and can be related to factors ranging from the socio-economic, psychological, or demographic, amongst others [5]. At the same time, the process leading to waste is often spread across many actors and frequently involves food that is close to its expiration date [5]. This means that waste can occur because of a poor optimization of the food chain, e.g., by storing food for too long, or not matching supply with demand. Information and Communications Technologies (ICTs), such as mobile applications, have great potential to reduce household food waste in urban areas given that they can be easily made available to a large proportion of consumers [6] and optimise the distribution and use of foods across the food chain. The proliferation of ICTs used for food consumption, whether in the form of platforms that enable easy and quick grocery shopping, takeaway food delivery,

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delivery of pre-measured food in recipe boxes in urban areas, suggests as well that many urban citizens are used to having their food consumption mediated by ICTs.

In this paper, we analyse household food waste using Installation Theory [8] and the MID approach [9]. We review literature gathered from Scopus, Web of Science, as well as Google Scholar and news sources, and recommend ways in which ICTs can help scaffold consumer behaviour to reduce waste. We use the term *food waste* to refer to "food appropriate for human consumption being discarded or left to spoil at a consumer level - regardless of the cause" [10]. It is distinct from food loss, which refers to waste or losses earlier in the food supply chain [2]. The majority of consumer food waste is generated within the household [12], which is why we focus exclusively on household food waste. Even more specifically, we consider food waste generated within urban households of young consumers living either alone or in a shared flat. Young adults aged between 18 and 34 tend to waste more food than older demographics [13] and are also more likely to use ICTs [14], making them the ideal demographic for our analysis. Similarly, urban areas are not only responsible for producing more food waste than other areas [13], they also offer networks and collaborative opportunities for the sharing of food amongst its members [15]. Considering that more than half of the world's population currently lives in cities [16], interventions and solutions in cities can contribute substantially to creating more sustainable food systems.

This paper proceeds in the following way: First, we discuss the nature of food waste and introduce our theoretical framework. We then present our problem analysis and segregate household food waste into three distinct stages and provide a detailed individual analyses of these stages. Finally, we distil our insights into a single 'ideal' mobile application to tackle household food waste, discuss the limitations of the work, and provide actionable recommendations for implementation.

2. Literature Review

2.1. The Impact of Food Waste

The negative consequences of food waste are numerous and varied, but can broadly be categorised into environmental, economic, and social impacts [13]. The impact of food waste on the environment is twofold [18]. Firstly, the overproduction of food poses an additional strain on scarce resources. The production of food requires resources such as land and water and is also connected to the emission of greenhouse gases. Secondly, agriculture is the largest consumer of water world-wide and as demand for food increases, the danger of water scarcity increases as well [19]. Simultaneously, up to 15% of all greenhouse gases are currently emitted due to food production [20]. Taken together with the trend of global population rise - predictions assume the population will reach 9.7 billion by 2050 [16] - the impact of the overproduction of food can be expected to intensify. It is to be noted here that food consumption is still distributed highly unequally across the globe, with average caloric supply per person in North America almost double of that in Africa in 2019 [21]. With higher levels of food supply, potential for food waste increases as well. The disposal of food waste in landfills additionally leads to greenhouse gas emissions and thereby promotes climate change. As food degrades in landfills, it releases both methane and carbon dioxide [22]. More so than carbon dioxide, methane is a key contributor to the warming of the planet as its impact on the climate over a period of 100 years is 34 times higher than that of an equivalent mass of carbon dioxide [23]. According to the US Environmental Protection Agency, only 25% of methane from landfills is captured and transformed into energy, whereas the rest is freely emitted into the atmosphere [24].

The social implications of food waste concern the problem of food insecurity. While globally over 820 million people still do not have secure access to food, one third of all edible food is lost or wasted [11]. Food insecurity reaches the entire globe, affecting citizens in both wealthy and poor countries, although to a different degree [11]. In some regions of the African continent up to 22.8% of the population is undernourished while up

to 8% of people in North America and Europe do not have sufficient access to food [11]. Under these circumstances, any wastage of food is a waste of resources that could be invested to alleviate food insecurity elsewhere. At the same time, the production of food that is not consumed puts an additional strain on the global food supply chain and exacerbates the difficulty of providing for a growing population, while possibly also increasing inequalities [18].

Finally, the economic dimension of the issue highlights food waste as a loss of economic value. In this way, the economic dimension can serve to quantify the impact on the environment, on society in general, and on the consumer as an individual. It will also serve to frame the issue and to put the problem into perspective: The FAO estimates the cumulative costs of food waste in the world to be around USD 12 trillion per year [25].

2.2. Drivers of Food Waste

Various drivers contribute to the continuous wastage of food. As our analysis focuses on urban areas in developed countries, we shall sketch an overview of the main drivers specific to these areas. Due to a decades-long increase in urbanisation, more citizens in the global north live in cities than in rural areas. In 2018, 82% of the North American population and 74% of Europe lived in urban areas [16]. Most agricultural production, however, occurs on farms in rural areas [18]. This physical distance and disconnect with the location of food production has led to a psychological disconnect with the sources of food and an increased lack of understanding of the labour and resources involved [2]. Particularly in the global north, consumers' lived realities are far away (both physically and metaphorically) from growing and processing of crops, animal husbandry, slaughtering of animals, and the processing of their meat; interactions with foodstuffs here usually begin on the supermarket shelves, were items are washed, cleaned, and mostly pre-processed.

Additionally, with an increase in income, dietary patterns have changed to include more products with a short life span such as dairy, eggs or meat and less starchy products [19]. The consumption of food with shorter life spans is further linked to a higher rate of food waste generation [19]. Lastly, the disconnect from food sources taken together with an increase in the consumption of non-durable food products positions cities as areas which are particularly vulnerable to an excessive wastage of food products [27].

A possible solution that has been put forward to tackle food waste in urban areas is the use of ICT technologies such as laptops, smartphones, and IoT devices [6]. In particular, the personal devices of users are a promising mediating tool to deliver interventions at the point of behaviour. This paper therefore critically evaluates existing mobile applications and provides a more comprehensive suggestion of a mobile app that can help urban environments create more sustainable food systems.

2.3. Theoretical Framework for Analysis

Two main theoretical approaches have been previously used to understand the reasons behind household food waste [28]. Psychology-oriented approaches have focused on identifying the cognitive and interpersonal factors that lead consumers to waste food [29]. The theory of planned behaviour [30] for example, has been used to explain food waste in terms of individual motivations and intentions [31]. Sociological approaches have instead focused on the influence of societal and external factors [28]. Social practice theory can be used to explain food waste as the product of household practices influenced by a wider economic and social context [32].

While psychology-oriented theories offer insights into individual psychological mechanisms that account for food-waste, they fail to explain why people's intentions to prevent food waste often do not manifest behaviourally [28]. On the other hand, social practice theory allows for a clearer understanding of this intention-behaviour gap but lacks a deeper explanation regarding the individual's interaction with environmental cues

[33][34]. Schanes and colleagues [28] note that a better comprehension of food waste behaviour stems from the integration of these two complementary views.

To analyse the consumer journeys that lead to unnecessary household food waste, as well as to develop the proposed interventions, we will apply the Multilayered Installation-Design approach (MID) [9]. Following MID, we use Activity theory [35] to trace the individual journey of stakeholders in food practices, identifying potential issues and defining the scope of our intervention. Activity theory (AT) understands human activity as a goal-directed trajectory from a given initial situation to a consciously represented, future state (*goal*). Attainment of the goal is driven by internal motives of the individual that finds satisfaction once the desired state is reached, and typically passes through several subgoals that are achieved incrementally. This conceptualisation of activity is, therefore, highly subject-centric and focuses on the individual perception and experience of action [9].

Installations are*:* "specific, local, societal setting[s], where humans are expected to behave in a predictable way" [8] (p. 15). Each installation is seen as composed of three layers: embodied competences (in the individual), material affordances (in the environment), and social regulations (within society). These three layers act together to scaffold and make human behaviour predictable within specific circumstances. The essence of any given installation is the activity it supports, and which (in principle) is aligned with the goals of its users [8].

Installation Theory as an analytical framework allows us to incorporate both psychological and social practice perspectives as it explains behaviour as resulting from environmental, social and individual factors. We use Installation Theory as an analytical framework for two reasons: Firstly, it allows us to bridge a gap within the theoretical literature, offering a more comprehensive understanding of food waste behaviour, by highlighting not only the consumer's intentions and practices, but also the material conditions of their environment (affordances) and the social regulation that can intervene in the determination of behaviour. Furthermore, Installation Theory is devised as a means to produce behavioural change in real-world situations and is optimal for the identification of real-world practical solutions. In this paper, we argue that ICTs, and mobile applications in particular, can be seen as objects that contribute to the installation, they are brought into to scaffold the behaviour of individuals. First, by extending and improving embodied competences. For example, a simple shopping list acts as an artificial extension of the individual's memory (cf. [7]). Second, the interface of an ICT can be analysed as a physical affordance scaffolding certain behaviours. Lastly, social norms also apply in digital environments, particularly when users interact with other users online [36], suggesting that the social layer of installations can potentially be leveraged by mobile applications.

2.4. Research Gap: The Three Stages of Food waste

Consumers interact with food items in various contexts and with various goals. Analysis is thus facilitated by segmenting household food waste into distinct stages. Several taxonomies have already been proposed, each outlining a path from the point of purchase, proceeding through consumption and ending in the disposal of uneaten food [12]. Differences in the models relate to whether certain specific activities, such as meal planning, meal preparation, or storage are classified as distinct phases or not.

We choose to build on the commonalities of these three models and adopt a simple three-stage sequence, composed of "Acquisition", "Consumption" and "Disposal" for our own analysis. To facilitate analysis under Installation Theory, we conceive of each stage as being defined by a central activity which *tends* to occur in a specific installation (although exceptions exist). "Acquisition" is thus defined as the activity of selecting and purchasing food for subsequent consumption, and the typical associated installation is the shop (in cities, often supermarkets). "Consumption" contains the activity of preparing and eating food which one already owns. "Disposal" includes activities in which consumers

dispose of food they own, which can include throwing it in the garbage, recycling it or giving it to someone else (see Table 1)

While meal planning and preparation are important, we will treat these activities as part of Acquisition and Consumption respectively, because they are directly instrumental to the overarching activity. Storage will be discussed throughout the entire sequence as an activity important for food waste at each stage.

In the following section, we will analyse typical user behaviours across the three stages and identify challenges and opportunities along the way. The analysis will be structured using the methodological lens of Installation Theory, shedding light on the physical affordances, embodied competences, and social regulations relevant for each step.

Table 1. The three stages of food waste used in our analysis. Each is associated with a central activity which is scaffolded by an Installation in our analysis.

Stage	Central Activity	Relevant Installation
Acquisition	Planning and Purchasing Food	Supermarket
Consumption	Preparing and Eating Food	Kitchen
Disposal	Disposing of Uneaten Food	Kitchen

3. Problem Analysis

3.1. Acqusition

In a modern setting, food for household consumption can be acquired in a variety of different settings, including supermarkets, local farmer's markets and increasingly online as well. Online grocery shopping still accounts for only a small fraction of household food acquisition according to Saphores and Xu [38]. Their recent analysis of data from the American Time Use survey indicates that in 2017, Americans were 24 times more likely to buy groceries in a store compared to online. In light of the COVID-19 pandemic, this might have changed significantly. Reporting on consumer research done by for-profit market research company Kantar, van Rompaey [39] reports that the share of fast-moving consumer goods purchased online in 2021 has risen to 7.2% in the US and 6.9% in Europe. In the end, while online grocery retail is an important part in managing food waste, we focus on physical installations as they still account for a vast majority of purchases.

Compared to other shopping locations, large supermarket chains are the biggest drivers of food waste behaviour in consumers [7]. At this stage, food waste typically results from the over-purchasing of unneeded products, which are not consumed, and are consequently disposed of [40]. Impulse buying, defined as a purchase decision made in-store with no explicit recognition of a need for such a purchase prior to entry in the store [41], is accountable for nearly 60% of overall purchases and leads to over-purchasing [42]. Impulse buying is consciously perceived by consumers as an unnecessary use of economic, mental and physical resources [43]; it is (often deliberately, with merchandising) fostered by the affordances displayed in supermarket alleys. The supermarket is thus analysed as the installation that leads to over-acquisition, and ultimately food waste.

3.1.1 Embodied Competences related to Acquisition

Over-acquisition of products in the supermarket has been associated with poor planning skills as well as memory deficits in consumers [37]. Consumers are affected by the

planning fallacy [44], defined as the underestimation of how much time they will need to complete a future task. In the context of food acquisition, consumers may underestimate the time needed to prepare and eat any given meal, leading them to purchase more food than they will be able to cook and consume before it expires [37].

In a supermarket, shoppers are also susceptible to the present bias [37], which refers to consumers' inclination to focus more strongly on pay-offs in the present than on trade-offs that may occur in the future [45]. In practice, consumers may prefer to make use of in-store promotions and select for variety, rather than purchase in line with planned consumption. On top of this, consumers may systematically underestimate the occurrence of unpredictable events and as of yet unplanned commitments, resulting in an overestimation of how many meals they will eat at home [37]. This is especially true for young consumers who often get involved in last-minute eating out for sociability purposes. Lastly, given that many consumers do not make use of a shopping list while in the supermarket [46], the inability to recall one's kitchen inventory typically leads to buying already stocked and unnecessary items that go to waste [14].

3.1.2 Physical Affordances related to Acquisition

Marketers have become increasingly aware of consumers' susceptibility to impulse buying and have been designing physical stores with the aim of eliciting these consumption biases through the infrastructure's physical properties [47]. Firstly, the overall architecture and layout of supermarkets typically increase the amount of time that is spent shopping there compared to other stores, such as smaller markets. This fosters over-acquisition and hence food waste [48]. Studies have also shown that eye-level shelves [48], in-store signage [49], and promotions [50] all increase the amount of sales, by appealing to consumers through attractive visual cues [48]. Supermarkets also increase overconsumption of food by displaying a wide variety of similar products (e.g., different flavours). This leads to over-acquisition by eliciting the diversification bias: consumers are attracted to buying products in bulk that contain variation, as they believe that in the future, they will want different flavour choices [51]. This, however, often leads to the partial consumption of goods, as buyers are more likely to consume their usual preferences, while disposing of disliked and unneeded options [37].

3.1.3 Social Regulation related to Acquisition

Social factors also influence purchases in the supermarket. Bevelander and colleagues [52] demonstrated that the amount of healthy vs. unhealthy food purchased by shoppers was proportional to the amount of healthy and unhealthy products purchased by a confederate, showing how people's purchasing choices partly result from social monitoring [52]. In supermarkets, shoppers see other people filling massive caddies with food as example behaviours; this is obviously not prone to encourage moderation. In sum, the abundance of tempting products, the affordance of huge caddies or bags, the forced trajectories along alleys full of "bargains", and the example of other consumers pushing massive loads of food all push to overconsumption. And these installations are skilfully designed by expert marketers and merchandisers precisely to maximise purchase.

3.1.4 ICT Solutions for the Acquisition Stage

Based on our analysis, an effective way to reduce food waste resulting from overpurchasing at the acquisition stage will be to counteract consumers' cognitive biases and memory deficits. Household inventory applications such as *No Waste* and *Plus Fridge Pal* can help consumers keep track of needed and unneeded items when shopping at the supermarket. Furthermore, these applications offer consumers a summary of their previous shopping and consumption experiences, displaying the items that have been previously bought and gone to waste, reducing the incidence of the present bias and planning fallacy,

as well as the diversification bias. A challenge associated with this approach is registering products and their expiration dates into the app as this potentially creates a large burden for consumers. A barcode scanner or integration with online grocery delivery websites could remedy this situation. Planning behaviour and quantity of food purchased can also be facilitated through portion-ready food delivery services, such as *Hello Fresh* or close to expiry sale apps like *Too Good to Go*, *MyFoody*, or *FoodCloud*. This allows consumers to choose from a variety of different recipes online. Ingredients for these are then delivered to their homes in the exact quantities required for cooking. Not only does this allow consumers to enjoy a large selection of products, but it also allows individuals to shop from their homes, reducing their susceptibility to over-purchase within the supermarket installation.

3.2. Consumption

During the consumption stage, consumers make decisions regarding preferred food to eat, which ingredients to use, and the quantity to cook, serve and eat [37]. Secondi and colleagues note that most food waste "could have been eaten if it had been better portioned, managed, stored and/or prepared" [13] (p. 3). An important part of this stage is whether consumers choose to reuse leftovers after a meal, as doing so may be one of the most effective ways of reducing household food waste [13]. We focus on the kitchen as the general installation for preparing and eating a meal, while acknowledging that there is a great variety between households. A family home, for example, usually has a shared dining table, while student accommodation may not.

3.2.1. Embodied Competences related to Consumption

Embodied interpretive systems such as experience, knowledge, and skills drive consumer behaviour in the kitchen. Memory of items available in storage affects the decision on what to eat or what ingredients to use when cooking. People can forget they have bought ingredients in the past and let them expire [37]. Perhaps more importantly, consumers lack the knowledge on how to use sensory skills (e.g. taste and smell) to interpret freshness of food correctly [12], increasing fear of foodborne illness and consequently waste [13]. In a large-scale diary and questionnaire study, Giordano and colleagues found that the most common reason cited for disposing of food was that it was "spoiled" [53]. This reason accounted for 45% of all waste in the study.

Similarly, Teng and colleagues identified the lack of knowledge around assessing edibility as the most frequent barrier to food waste prevention in a Taiwanese sample [54]. Fear of spoiled food especially affects fish, meat, or dairy products, which have a large environmental impact during their production and are thrown away more often compared to other food items [53]. Lacking sensory skills to determine food freshness themselves, many consumers rely on food labels such as "best by" dates. White and colleagues found that eating food after the date displayed on the packaging was perceived to be dangerous, even though in many cases there is no risk [56]. Some labels such as "sell by" are created to suggest the date by which the store should stop offering the product. "Best by", "best before" and "use by" are estimates of dates of when the product will maintain its highest quality [57]. This does not mean that the product is no longer safe to eat after this date [37]. Similarly, wrongful perceptions of health risks associated with eating leftovers influence whether they are thrown away after a meal [7]. Hence, misunderstood food labels in combination with lack of food appraisal skills encourage people to dispose of edible food too early [27]. While aversion to spoiled food accounts for the majority of food waste at this stage, it should be noted that pure preference for novel and freshly prepared meals also plays a significant role [53].

Beyond memory and appraisal, cooking skills also play an important role in food waste. Unappealing leftover food can be transformed and seen as "fresh" again by a process of rediscovery, re-evaluation and preparation in the kitchen [59]. An illustrative example of this is using leftover chicken bones to make a broth on the following day.

Consistent with this, cooking skills allow consumers to make better use of leftover ingredients, preventing food waste [60]. Lastly, cooking competencies also help avoid burning food and cooking excessive quantities that are then wasted [27].

3.2.2 Physical Affordances related to Consumption

The amount of storage space, the size of the refrigerator, and the colour, size and material of plates used for servings and storage all influence consumption behaviour in the kitchen [37]. Consumers may forget to consume items close to the expiration dates if newer purchases are stored more visibly in their inventory [56].

While we found no research investigating the effect of cooking appliances on food waste, we expect superior kitchen equipment to come with cooking competencies, which in turn can decrease food waste [27]. Particularly, we expect that simply having access to durable and easy-to-use storage boxes ("Tupperware") for leftover foods would increase reuse especially if there were easy systems for signalling dates of consumption.

Finally, the physical appearance of food items such as fruit and vegetables or damaged packaging affects consumers' decisions to dispose of them, even when still edible. Consumers fear imperfect food might be unsafe to eat [56]. Notably, this mechanism also affects *food loss*, since supermarkets often throw out "ugly" foods instead of displaying them. A number of digital solutions have sprung up to tackle this problem (for example OddBox - a vegetable delivery service that only ships "ugly" foods). While more research is still required here - the popularity of such services suggests that aesthetic norms around food have the potential to change.

3.2.3 Social Regulation related to Consumption

The social composition of a household can have a big influence on food waste. In a review of relevant national studies, Hebrok & Boks [61] found that families with children produce less food waste per capita than other households (albeit more in absolute terms). Furthermore, the lifestyles of younger consumers are more commonly characterised by "pleasure, improvisation and social activity", correlating with higher proportions of food waste [61]. Thus, the role of the *gatekeeper* (see [62]), that is, the person who buys or prepares food for the household is crucial. Families tend to shop for and prepare meals for the entire household. In flat shares, individuals usually shop for and prepare food independently, but there is the opportunity for shared shopping, cooking, or pooling food items to prepare a meal. Single-person households are the least well posed to share or pool resources when it comes to acquisition and preparation of food.

Social conventions, social representations, and culture constitute another layer that influences behaviour in the consumption stage both directly and indirectly. In a qualitative study of 15 UK households, Graham-Rowe and colleagues identified "good provider" norms as a significant barrier to minimising food items [17].

People want to avoid feelings of guilt or failure to meet others' expectations of what it means to be a good host or provider, leading them to over-prepare meals, serve excessively big portions and avoid properly storing leftovers while guests are present [17]. Such norms can also encourage obesity and/or waste, particularly when parents aim to satisfy their children instead of focusing on a balanced diet [63]. Building on this work, a survey of 643 consumers in Australia and Singapore found that good provider norms suppressed intentions of avoiding food waste in Australia, but not in Singapore, possibly due to the higher emphasis placed on thrift in the latter country's culture [64].

While 'good provider' norms can drive food waste by increasing the amount of food prepared by the cook, other social norms influence eating behaviours in the guests or consumers. In a cross-cultural qualitative study of Czech and French restaurant guests, a large attitude-behaviour gap was found, where most respondents reacted favourable to the idea of asking for a 'doggy bag' with leftovers at the restaurant, yet very few had ever done it themselves [65]. This gap was mainly explained in terms of social norms around

restaurant etiquette. More relevant to our chosen installation of the dining table is the norm, shared in many cultures, of "finishing what one has started" - i.e., eating all the food on one's plate [66]. The relationship to food waste here is somewhat less clear. On one hand, someone who finishes their plate leaves less food that may be thrown away. On the other hand, if I am already full, the rest of my food may be more usefully eaten tomorrow, rather than overeating today. With this, it is important to bear in mind that cultural norms around finishing plates can vary quite starkly, and finishing a plate may be socially undesirable in particular contexts as it can be interpreted as gluttony or signalling to the host that one has not yet had one's fill (and thus drawing into questions their generosity).

3.2.4 ICT Solutions for the Consumption Stage

Food waste behaviour at the consumption stage is associated with consumers' aversion to foodborne illness, lack of knowledge on how to interpret food freshness and food labels, memory deficits of inventory and social norms. Creating solutions that facilitate access to inventory, food appraisal and cooking skills and storage competencies can support consumers to reduce food waste at the kitchen installation.

Applications that offer consumers an overview of their inventories (such as *NoWaste* and *Plus Fridge Pal*) can prevent food from being forgotten and left to expire. Such applications may also help interpret labels correctly and recognize the freshness of food, but their success depends on how rigorously users perform product entry into their inventory. Avoiding unsafe food recommendations and overreliance on the side of the users (i.e., an app labelling an item as edible that has expired), as well as correctly accounting for natural variations in produce will be a challenge. Additionally, mobile applications such as *Plant Jammer* may suggest recipes to use up food which is soon to expire. These recipes can also suggest the correct number of portions to prepare to avoid food waste. Lastly, apps can be used to create social awareness about the impact of food waste, creating a social value for sustainable behaviour. Within the context of leftovers, the above functionalities may help reduce perceptions of health risks and distaste by displaying positive information about the nutritional value of leftovers as well as recommending simple ways in which to turn leftovers into another meal.

3.3. Disposal

During Disposal occurs once consumers decide to not keep a certain food. Generally, individuals are faced with the choice of throwing food in the garbage, recycling it (for example by composting) or giving it to another person. While composting serves to alleviate some of the negative environmental consequences of food waste, it doesn't directly reduce food waste itself and is thus not at the core of the intervention proposed in this paper. The correlation between composting behaviour and food waste itself is also still poorly understood. A study of food waste across the EU-27 countries found that individuals who report sorting their waste also report significantly lower levels of food waste [13]. However, there may also be backfire effects in play: 41% of a sample of U.S. households reported that, because they compost, they aren't bothered by wasting food [46].

In this paper we focus on food sharing behaviours when it comes to disposal. Specifically, we view the act of gifting leftovers to other people who may still eat them as a disposal behaviour that may prevent food waste. Nonetheless, it is of course not difficult to include composting in the app's functionality at a later stage, for example by including prompts when food items registered in the app are ready to be composted, how this should be done, how the compost should be maintained, and so on.

The most relevant installation for disposal is the kitchen, although in the case of food sharing, the relevant physical space can extend to include spaces where food is exchanged between strangers, including digital spaces associated with such practices (e.g., [7]).

3.3.1. Embodied Competences related to Disposal

Embodied competences needed for effective sharing of leftover foods are largely identical to ones identified in Section 3.2.1. Identifying that food can be consumed requires some of the embodied skills discussed, but beyond that, few additional competences have been identified that enable food sharing with strangers. Social competencies are likely to play a role, and prior social relations are an important enabling factor for food sharing [67]. It therefore stands to reason that strong interpersonal skills may influence food sharing. All research identified for this study, however, analyses the issue from a social norms perspective, and is therefore discussed in the following sections.

3.3.2 Physical Affordances related to Disposal

Physical affordances relevant to food sharing are those that allow individuals to access a social network where giving away food becomes possible and convenient. In a comparison of rural and urban low-income environments in the US, Morton and colleagues found that rural neighbourhoods are more likely to participate in reciprocal nonmarket food exchanges - i.e., by giving food to family, friends and neighbours [68]. Urban low-income neighbourhoods, on the other hand, were more likely to access food through the redistribution economy [68]. To fully analyse the physical affordances that separate urban form rural contexts is beyond the scope of this paper, but it seems safe to assume that rural neighbourhoods are structured to encourage more interaction with one's neighbour, which may encourage the sharing of surplus food and that which is close to expiry, while urban environments rely more on digital technology and formally created solutions. This strengthens our focus on using ICT to reduce food waste in urban environments.

While there is little research on the influence of the immediate physical environment on food sharing behaviour, there are a few obvious considerations. Firstly, the availability of food storage devices (e.g., Tupperware) is a practical limitation to food sharing. Certain foods cannot be given away without a container, and consumers may be hesitant to give away high-quality or expensive containers with the food - uncertain whether they will receive them back. Secondly, in the context of sharing food with a predefined group (for example within the household or at work) - the designation of specific places for shared food is a likely enabler of more food-sharing behaviour. Having a "shared shelf" in a fridge signals to others that the food can be taken, and may encourage people to leave leftovers behind, rather than throw it out. Moreover, community fridges can further sharing behaviours of perishable goods beyond the limitations of the household (see e.g., [69] for an early trial).

It should be noted that simply sharing food within a household does not automatically reduce food waste. Environmental attitudes, household food management skills, and general attitudes towards collaboration are important mediating factors ([70]. It is possible that intentionally sharing food with persons outside the household is thus more effective, since the receiving party is more likely to plan around consuming the food compared to a household member simply finding food on a "shared shelf".

3.3.3 Social Regulation related to Disposal

Social norms surrounding leftovers can act as obstacles to food sharing behaviours. Some groups may see leftover food as "dirty" and even consider it shameful to reuse [67]. Specifically, once food has been designated as "waste" it becomes socially unacceptable to consume it [71]. Similarly, qualitative research suggests that once food has been designated as "waste" or "leftovers" it immediately becomes less appealing to consumers, which contributes to an aversion to accepting food from strangers. [59].

Lazell [67] found that in a UK university context, prior social relations between students were crucial for enabling the trust necessary for sharing food. While Kniazeva and Venkatesh [72] have argued that sharing food is associated with shared identity formation and forming social relations, Lazell [67] found that in practice, the simple desire to share food is not enough to justify forming social bonds strong enough to enable food sharing

behaviour. Similarly, sharing food with neighbours and the wider community is likely to depend on notions of common identity and trust shared with those individuals (c.f. [7]).

3.3.4 ICT Solutions for the Disposal Stage

While the effect of composting on food waste is ambiguous, sharing food presents a great opportunity to reduce food waste. [7]. In an analysis of left over and close to expiration food sharing platforms, Choi and colleagues established that such platforms may benefit the end consumer as well as other economic stakeholders, such as the retailer and the supplier, while reducing food waste [73]. Other applications re-integrate food waste into the production cycle and use it to feed animals [74]. Available solutions aimed at household consumption include *EquoEvento, FoodSharing.de, IFoodShare, LastMinuteSottoCasa,* or *S-Cambia Cibo*. While highly informative for our intervention, these commercial applications do not perfectly translate to the household case as they are mainly driven by financial incentives for the various stakeholders. Our analysis suggests that to effectively encourage food sharing among households, applications need to not only establish a digital marketplace in which to exchange food, but must also alter the social norms surrounding food waste and help build relationships between food sharers. In moving beyond the household, establishing trust and social bonds between food sharers is especially important. We see two main ways in which ICTs can achieve this. First by leveraging insights from Social Identity Theory [76] and creating a salient in-group identity, for example by emphasising that food is being shared with members of the same local neighbourhood. Secondly, trust can be created by allowing users to rate and review the digital profiles of other food sharers [77]. Taken together this may help overcome the barriers associated with food sharing and even create new persistent relationships between agents committed to reduce their food waste by sharing [75]. Table 2 provides a summary of the analysis presented in this section.

Table 2. Different Mechanisms of Food Waste and Opportunities for ICT Solutions.

Phase	Installation Component	Mechanism	Example	ICT Opportunities	Source
Acquisition	Embodied Competences	Planning Fallacy	Consumers underestimate time needed for food preparation and thus plan for more meals than they can make	Portion Ready Food Delivery	[37]
		Present Bias	In store promotions factor more heavily into decision making, compared to planning for future commitments	Shopping Lists	[37]
		Poor Memory of Inventory	Not using a shopping list, consumers buy what they already own	Kitchen Inventory Management	[46]
	Physical Affordances	Supermarket Physical Layout	Encouraging more time spent in the store	Direct delivery	[48]
		Attractive Visual Cues	Promotional signage	ibid	[48]
		Diversification Bias	Purchasing bulk items with different flavours	ibid	[51]

	Social Regulation	Social Monitoring	Adjusting purchases towards observed purchases of other shoppers	ibid	[52]
Consumption	Embodied Competences	Poor Memory of Inventory	Forgetting what one has in the fridge means one doesn't plan to use it	Kitchen Inventory Management	[37]
		Sensory Skills to Interpret Food Freshness	Smelling Milk to determine if it has gone off (rather than relying on the label)	Guides to help consumers discern food freshness	[12]
		Knowledge of Food Labels	Throwing out still-healthy food on the 'sell-by' date	Explanation of food labels	[27]
		Perception of Health Risks	Overblown fear of eating some out-of-date products	Guides to help discern food freshness	[7]
		Cooking Skills	More creative and consistent use of leftovers	Recipes and other Cooking help	[60]
	Physical Affordances	Storage Space	Placing newer food items at the front of the fridge leads to forgetting older purchases in the back	Kitchen Inventory Management	[56]
		Serving Equipment	Plate colour affects serving size	Tips on how to serve food	[37]
		Cooking Equipment	Better capabilities for reusing leftovers (supporting cooking skills)	Tips on how to best prepare food in recipes	[27]
	Social Regulation	Good Provider Norms	Preparing too much food to be seen as a generous host	Nudging cooks to create appropriate portion sizes	[17]
		Cultural values around leftovers	Shame around reusing leftovers	Awareness raising campaigns to encourage the reuse of leftovers	[71]
Disposal	Embodied Competences	Interpersonal Skills	Prior relationships enable food sharing behaviour	Facilitating social interaction	[67]
	Physical Affordances	Urban Redistribution Economies	Food Sharing Platforms	Creating a new platform for sharing food in a local context	[73]
		Shared Food Spaces	Shared shelf in a communal fridge	Creating a new platform for sharing food in a local context	[69]

Social Regulation	Cultural Attitudes towards leftovers	Reusing leftovers may be seen as a socially undesirable sign of poverty	Signaling that leftover use is virtuous	[67]
	Food Sharing Norms	Rural neighbours are more likely to share food.	Enable new norms through online community	[68]

4. The Problem Scope: Applying Activity Theory

Based on the solutions suggested at each food waste stage, we have distilled a list of 12 key features with which mobile applications can help reduce food waste (see appendix). We propose condensing these 12 features into four major functionalities, which, when integrated into a single mobile application, may scaffold consumer behaviour at each stage of food waste to optimally reduce wasteful behaviour: 1) Inventory management, 2) Smart recipes, 3) Portion ready food delivery, 4) Food sharing hub (see table 3). This one-stop-shop smartphone app sketches an ideal version of synergetic functionalities and integration and is intended to illustrate how powerful & effective a smartphone-based intervention focusing on food-waste could be. In practice, it may not be possible to deliver the app in its entirety, or it may be more convenient to deploy parts of its functionality in already existing systems.

Table 3. Proposed functionalities for applications to reduce household food waste.

App Functionalities			
Smart Inventory	Smart Recipes	Food-Sharing Hub	Portion-ready Food Delivery
Create grocery lists based on past consumption and current inventory; scan barcodes to automatically enter items into the system.	Find recipes based on inventories and soon-to-expire food	Manage common inventory for food shared within flat	Order ingredients for specific meals to be delivered straight to the door
View information on how to store purchased items correctly	Track leftovers and find recipes for creative reuse	Access digital marketplace to share leftovers with members of the wider community	View information on how to store purchased items correctly

View information on when purchased items should actually be disposed	Adjust recipes for ideal portions for every user	See and rate personal profiles of other food sharers	View information on when purchased items should actually be disposed
Have clear overview over available foods in the inventory			
See statistics on past food waste, including monetary and environmental impact			

4.1 Inventory Management

The ideal mobile application should allow users to log all food items in their inventory, and to create smart grocery lists based on this information. Additionally, the ideal application would present information for each food item on the grocery list, explaining how to properly store the item, how to tell when it has gone off, as well as how frequently this particular food has been wasted by the user in the past. Such functionality would facilitate proper meal planning and help reduce over-purchasing in the supermarket, while also preventing premature disposal due to ineffective storage or wrongful assessment of food safety. The app would predict when certain food items are due to expire (for example based on information on food type and expiration date entered by the consumer) and alert the user before this happens, so they can incorporate these ingredients in the next meal. By also displaying historical data on food items thrown out in the past, we hope to further raise awareness of the food (and money) wasted by consumers every week. Of course, the success of this functionality depends on users actually logging their inventory. By allowing users to make grocery lists within the application and adding any item which has been ticked off that list directly to the inventory, we could reduce the effort connected with tracking one's inventory and capitalise on the habit of making grocery lists, which already exists for many consumers [46]. Repositories of product barcodes or QR codes can also be leveraged to facilitate product entry. Furthermore, the advancement of new technologies and the development of smart fridges could automatically record the food items that users have bought and stored within their kitchen, alleviating the effort on the user's side.

4.2 Smart Recipes

The Another important factor for preventing food waste is cooking capability [12]. Based on the items on the inventory list that are about to expire, the ideal application would suggest recipes for meals that can be prepared with the available ingredients as well as suggest complementary items to buy, if necessary. This presents an excellent opportunity to integrate existing recipe databases (e.g., *BBC good food*) into the functionality of the app. This will not only increase functionality for users as recipes can be tailored depending on the number of servings, time available and level of difficulty, but can also increase uptake from existing users of the recipe databases, encouraging sustainable behaviours further. It can further also lead to utility for recipe websites, as more recipes focusing on using leftovers will be created.

Overall, this will enable consumers with low cooking skills to use all the ingredients they buy, in the correct amount, as well as avoid any cooking mistakes that may lead to food waste. Additionally, the application would let the user log whether all of the

prepared food was eaten. If not, it could add the leftovers directly to the inventory list and automatically suggest ways to use them in future meals. This would help consumers to reappraise leftovers as desirable and avoid unnecessary waste at the consumption and disposal stage [59].

4.3 Food Sharing Hub

As discussed, food sharing has the potential to prevent a lot of food waste, but also faces major challenges in overcoming social norms related to accepting leftover food from strangers [67]. The ideal app should include a food sharing hub, which not only acts as a marketplace for users to donate and pick up leftover food items (similarly to existing apps Olio or Too good to Go), but also leverages existing social ties between regular food sharers. We propose that it should have features both geared towards food sharing within the household, as well as for the broader neighbourhood. Within a household, the food sharing hub would be linked to each user's individual inventory list. Users should be able to drag individual food items to a shared inventory list, notifying all cohabitants of the flat share. To encourage food sharing outside the household, we suggest letting users set up personal profiles with pictures and having others rate the quality of the food shared. While this runs the risk of discouraging users from sharing food in the first place, we believe transparent ratings to be an invaluable tool in fostering trust between strangers, which in turn is necessary for food sharing [67]. Secondly, the app should emphasise that food is being shared with people in the neighbourhood, to further increase social cohesion and trust between users.

4.4 Portion Ready Food Delivery

Finally, we propose to integrate our mobile application with a portion-read food delivery service such as *Hello Fresh*. Users would be able to plan meals for the upcoming week and get the ingredients delivered directly to their door in the perfect quantities. This feature would allow consumers to overcome the diversification bias in the supermarket, as they are offered a wide range of choices daily and would equip them with the necessary tools and information needed to correctly prepare meals. The fact that the ingredients are portioned would also result in fewer leftovers which may be wasted.

Ideally, this function could be integrated with the other three functionalities. Meals could be suggested based on food items already found in the inventory. Once the ingredients for the planned meal arrive, they could also be added to the inventory automatically, and the matching recipe activated.

5. Discussion and Limitations

Throughout this paper we identified sources of food waste within urban households of young consumers. Using Installation Theory, we discussed the physical affordances, embodied competences and social regulations that influence consumers throughout the process of acquisition, consumption and disposal of food. We focused our analysis on the supermarket and kitchen, considering these as the most important installations where these processes tend to occur.

Based on the analysis, we proposed an ideal mobile application that can help reduce food waste by scaffolding relevant behaviour. This ideal app is built around four key functionalities: 1) A comprehensive inventory management system, 2) a smart recipe generator, 3) a food sharing hub, and 4) a portion-ready food delivery service. The app aims to reduce food waste that's dependent on the final user. Through its smart inventory system, it enables users to keep track of the items they buy and store, enabling them to make informed purchasing decisions at the supermarket based on other ingredients they already have as well as their past cooking and consuming behaviours, resulting in less impulsive purchases that ultimately lead to waste. Further, through its smart recipe function, it also

guides users in the process of cooking with the ingredients they have, maximising their existing food ingredients, and minimising new food purchases. The introduction of a food sharing hub further reduces food waste at a wider household level by leveraging social ties and enabling members of a community to exchange needed food items without having to engage in new wasteful food purchases. Finally, integrating a portion-ready food delivery system would facilitate the reduction of food waste at all phases, as it would allow ultimate users to purchase strictly necessary ingredients, as well as cook with these in an efficient manner, reducing disposal overall.

Possibly, the most important limitation of our solution is that it depends almost entirely on consumers' willingness to use the mobile application. Real world ICT solutions face the threefold challenge of beneficially scaffolding user behaviour while encouraging enough individuals to regularly use the application and somehow being financially sustainable. We have here only considered the first of these three challenges. In this regard, it will also be important to take into account people's diverse engagement with ICTs [78], particularly in relation to food-related behaviours [79], and the interaction between devices [80]. Similarly, issues of data sharing and privacy may become relevant.

Secondly, while we have identified key behaviours that contribute to household food waste, counteracting them is not necessarily guaranteed to reduce total food waste. Treated in isolation, some measures may only displace food wasted. For example, by cooking smaller portions at each meal, one may waste fewer leftovers, but end up with more raw ingredients which spoil in the fridge. Any kind of reduction in household food waste needs to eventually translate into a reduction in food acquisition by the household. And even then, saved food may still be wasted earlier in the supply chain, for example because supermarkets keep ordering the same amounts.

Thirdly, household composition and living arrangements more generally are a significant influence on how people shop and what opportunities for food sharing are available to them, but we have so far only discussed the influence of the *gatekeeper* who does the shopping and cooking for the household. The effectiveness of interventions aimed at social regulation, for example, may be lower in single-occupancy households. Similarly, technological solutions require seamless integration in households where foodstuff is bought and consumed by multiple people. It will thus be crucial to investigate the efficacy of ICT solutions aimed at reducing household ways in embedded, *in situ* investigations that can document the complexities, opportunities, and shortcomings of these solutions as they emerge naturally. Moreover, aggregate-level data on ICT-based solutions to reduce food-based needs to be collated to understand take-up, user profiles, and usage behaviours, both to increase user numbers and to better tailor solutions towards existing users.

Ciaghi & Villafiora [6] have commented on the inherent difficulty of saving food at the household level - due to the food items being kept in small quantities and very close to their expiration date. It is thus worth taking a step back to locate the technological solution offered in this paper in the wider political, social, and economic context of food waste. We agree that it will not be possible for a single mobile application to tackle household food waste on its own but see it as a starting point in facing a problem that requires many different approaches being enacted in parallel.

6. Conclusion

With a growing global population and food production set to be affected by progressing global warming, household food waste is a big issue to be tackled at the systemic level and the individual level. This is particularly pressing in developed countries with 92 kg of food wastage per head per year in the EU for example [3]. This paper proposes an intervention using personal ICTs to help consumers reduce household food waste during food acquisition, consumption, and disposal. Based on a detailed analysis of consumer activity, we provide a set of recommendations rooted in the extant empirical literature and aimed at improving processes in the physical space, developing personal

competences of users, as well as updating social and cultural norms. These ideas are leveraged in the sketch of a prototypical, integrated mobile application that combines the insights from our analysis and delivers them directly to the user. This combined, holistic approach offers a promising route for individuals and social groups to reduce the amount of household food waste they produce, and their ecological impact. Future research should develop and prototype the application functionalities proposed in this paper. For the policy & stakeholder level, this paper serves as a work-in-progress and comprehensive review of opportunities for consumer-based action interventions to reduce household food waste.

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