Rethinking Domestic Food Consumption through a Multi-modal Open Pantry

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ABSTRACT

The fast-paced lifestyle and the conveniences of urban food storage contribute to an increase in domestic food waste, wherein we end up not consuming everything that we buy. This issue has been tackled within HCI through different awareness tools; however, the design of domestic food storage in itself has received limited attention from designers. We present *FoodChestra*, a smart open pantry that displays perishable food items in shared households. *FoodChestra* supports multimodal interactions and offers timely feedback to help users understand and reflect on their shared shopping and eating practices. In this pictorial, we present the key design decisions that were undertaken to develop the five main components of *FoodChestra*. Through this work, we aim to inspire new design thinking for reimagining the food storage systems of urban households that can encourage people to reflect on their food consumption practices.

Authors Keywords

Human-food interaction, Tangible Interaction, Multi-modal feedback, Food consumption, Food waste.

CSS Concepts

• Human-centered computing • Human computer interaction (HCI)

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Figure 1: *FoodChestra* is a smart open pantry that displays perishable food items in shared households. FoodChestra supports multimodal interactions and offers timely feedback to help users understand and reflect on their shared shopping and eating practices

INTRODUCTION

According to the Australian Food Bank [19], Australian households account for one-third of the food waste in the whole food cycle [42] and the situation is no different globally [25]. Fast paced urban lifestyle and the prevalent use of quick, 'on-the-go' food practices results in more food purchases than what one would typically consume. These additional food purchases eventually go to waste if not eaten on time. Moreover, widely prevalent food storing practices that occur within a layered pantry and in the depths of the refrigerator further limit our interaction with food, particularly with perishable food items that have a limited lifespan. Such practices thus result in *'out of sight, out of mind'* conditions that lead to more domestic food waste [4].

HCI research has tackled this issue by creating awareness tools to help people reflect on their food practices [1,31,36]. For instance, works like *BinCam* [36], *Grumpy Bin* [1] and *Winnow* [43] allow individuals to reflect on their food disposal behavior by capturing and sharing photographs of their domestic food waste on social media. *Euphoria* [39] is a social food waste logging app that allows users to manually log their food waste and the reason behind the wastage. While such systems can encourage reflection, the burden of daily logging can be demanding on users and it could lead to guilt and embarrassment, particularly in a social setting [36]. Besides, these approaches tackle the problem only after it has occurred, i.e., after the user has decided or discarded the food due to certain reasons.

In the other spectrum, works also exist that raise awareness on what is available in the refrigerator in order to prevent overbuying [6,23]. For instance, *Smarterware* [2] is a smart food storage solution that uses smart color coded tags to alert users about fridge items that are about to expire. *Bump Mark Label* [38] is a smart sticker that conveys the progression of food through different reactions. Samsung's Family Hub refrigerator uses built-in cameras to allow users to check their fridge content prior to grocery shopping through a smartphone application. Finally, *Lyssna* [31] is an innovative hearing aid that allows users to listen to the contents of the refrigerator to understand the state and amount of the food.

Alongside these digital solutions, existing research also advocates low-tech and tangible solutions to help individuals reconnect with their food [15,32]. For example, Farr-Wharton and colleagues [5], conducted a cultural probe study that involved color-coding of the fridge items based on their category (e.g., fruits and vegetables) to reduce the domestic food waste. Their findings indicate that simple paper-based color-coding raised participants' awareness about the availability of food items in the fridge, especially for those household members who were not directly involved in the shopping and storage phases. This work inspired our design thinking to look beyond digital solutions for raising awareness on food storage and consumption. Finally, we were also surprised by the limited explorations on the actual food storage systems and we see here an opportunity to rethink domestic food storage beyond refrigerators and closed pantries. We envision that by bringing the food out of the closet and making it publicly visible could influence our decision making around food and could help to tackle the issue of *"out of sight, out of mind"*.

Drawing on this idea, we present *FoodChestra*, a smart open food pantry that utilizes a pulley-based mechanism with specially designed bags to display different food items through its open furniture-based design and provides abstract feedback to the users about their food consumption behaviors. The system also presents a timely reminder when a food item remains untouched for 24hours. *FoodChestra* creates opportunities for both shared and self-reflection by moving food items out of the closed storage into an open style storage system while encouraging interaction with it through its multimodal capabilities. This pictorial reflects on our design journey and highlights the key design decisions undertaken behind developing an open food pantry. We contribute by presenting the vocabulary and key components required to design an open food pantry, which we hope will inspire HCI and TEI researchers towards imagining creative storage solutions and innovative multimodal ways of tackling domestic food waste.

FoodChestra

/fuːd ˈɔːkɪstrə/

FoodChestra is a tangible system that aims to encourage reflection on food consumption and food waste behaviors in urban shared households through multimodal interactions. The name *FoodChestra* stands for "Food Orchestra" as it allows users to orchestrate their own food pantry.

FoodChestra follows an open pantry structure and utilizes a pulley-based mechanism to openly hang perishable food items in the shared living space. The system affords multimodal interactions - auditory, visual, tactile and olfactory, which altogether allows users to create an orchestra of their food practices with every interaction. *Foodchestra* also has built-in sensors that detect if the system has not been used and then provide a subtle auditory feedback in the form of knocking sound, nudging users to attend to it in a timely manner.

Figure 2: *FoodChestra* is a novel food storage design featuring an open pantry to store different food items in specially designed bags.

FOODCHESTRA IN ACTION

We explain the working of *FoodChestra*, through a fictional user "Alan" who has recently bought *FoodChestra* (refer to Figure 3).

1. Alan first unboxes the *FoodChestra* and takes out the flat packed structure.

2. He sets up the structure by attaching the pulleys and ropes to the rod.

3. He then attaches the bells and weight bags to different ends of each rope.

4. He fills the bags with food items and attaches them on the ropes.

5. He attaches the knocking system to the structure and plug in the adapter to activate the system.

6. After some time, Alan feels hungry and grabs a banana from *FoodChestra* that triggers the bell to ring.

7. His partner, Sarah, hears the ringing bell and comes out to see who is interacting with *FoodChestra*.

8. While there, Sarah also grabs an orange to eat and briefly chats with Alan.

9. Next day, the knocking system detects that the bag of bread remained unattended in the last 24 hours, thus it triggers the knocking sound.

10. Alan hears the knocking and realises that the bread has not been eaten so he grabs one to eat.

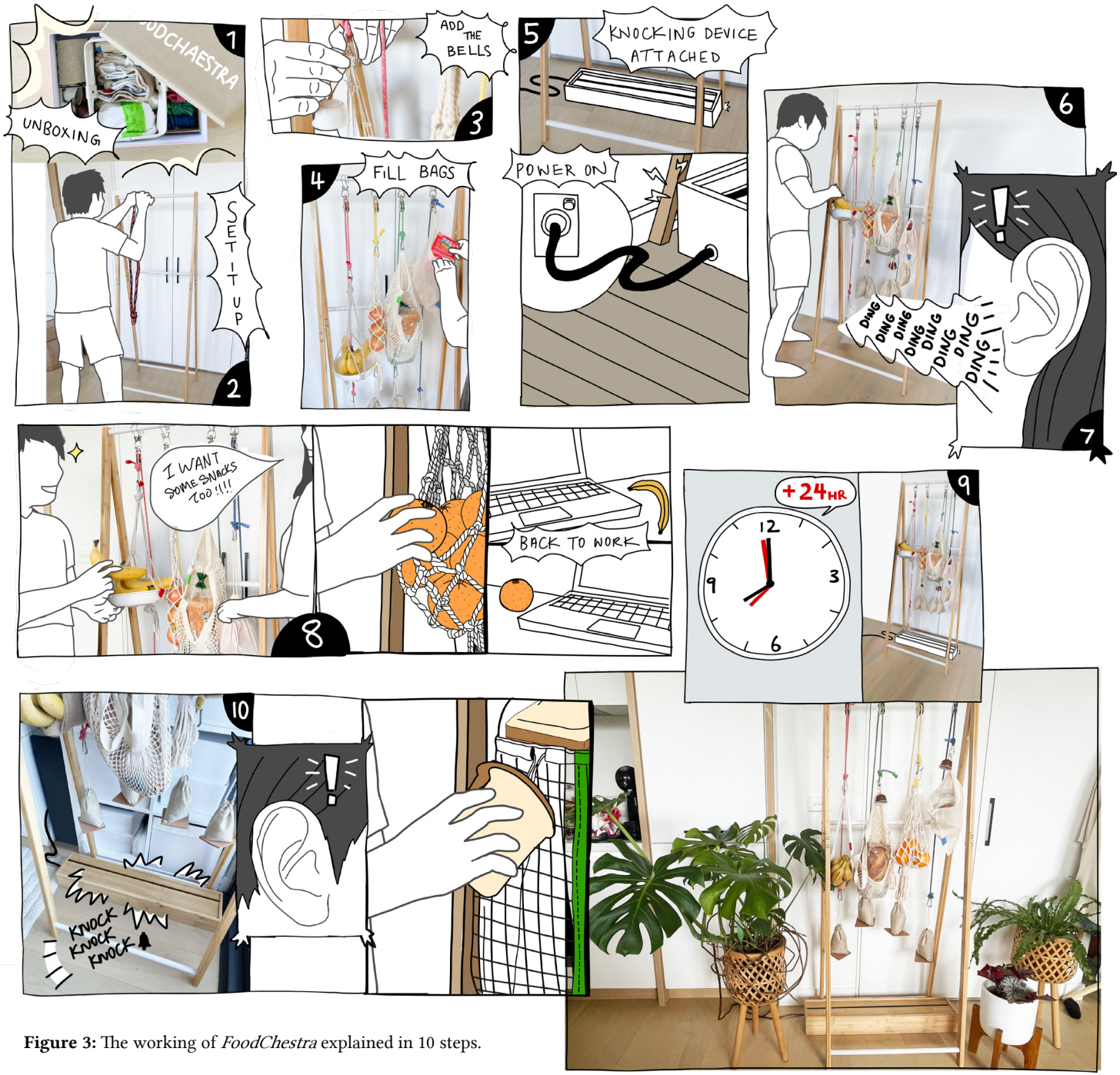

Figure 3: The working of *FoodChestra* explained in 10 steps.

TOWARDS DESIGNING AN OPEN FOOD PANTRY

We employed a Constructive design approach [18] to develop *FoodChestra*, where the need to design was guided by the gap we formulated from the existing literature on food waste and other domestic food practices as well as our curiosity to further explore multimodal Human-Food Interaction [17] space.

Constructive design is a variation of the research-through-design [40] that puts emphasis on the "imagination" and "making", as a way of understanding and engaging with a research context [18]. Koskinen et al. note (ibid) that in constructive design research, designers "imagine new realities and build to see whether they work. The main criterion for successful work is whether it is imaginative in design terms. Theirs is a science of the imaginary" (p.42). However, often this knowledge remains implicit or hidden inside the constructed artifact and requires careful unpacking through what Schön describes as *"reflective conversation with the materials of a design situation"* (p.132). As such, the knowledge generated in this process could include: novel perspectives on a problematic situation; implications on how to operationalise certain theory in an artifact; knowledge on how to handle different types of challenge during design; and finally the designed artifact itself that advances both the context of inquiry and design space [8,18]. Drawing on this, this pictorial attempts to articulate and communicate the generative reasoning behind each design decision that led to the final design of *FoodChestra*.

When we started this research, we had the following questions in mind:

Q1. How can we design a multimodal nudging system to raise awareness on one's domestic food practices?

Q2. What are the key design considerations while designing an open pantry?

Q3. What elements of multimodal feedback are crucial in bringing attention to one's domestic food habits?

Answering these questions was not easy as we could not find a vocabulary or framework that could guide the design of a multimodal open pantry. Instead, it required several iterations and constant discussion amongst the team members. The design of *FoodChestra* took us more than 8 months to complete as work needed on multiple fronts starting with identifying the right materials to form the foundation for the open pantry; selecting the kinds of food to store in the open pantry; choosing the method and materials to store food items; exploring different forms of feedback and finally assembling all these things together.

Each design decision unfolded sequentially and was guided by the previous choice. The lead author also used the system for over a month at her place to identify and overcome usability issues. Specifically, the intention was to identify and test the sturdiness of the pantry design by trying out different amounts of food as well as to finalize the auditory feedback methods, i.e., how often should the knocking be and how loud it needs to be and what kinds of bell to use in the design. Since this project involves real foods with different shelf life and storage methods, using it in practice while we were designing was necessary to understand the intricacies of the system better. For example, we could experiment with different foods to understand what material to choose for the bags and how breathable it needs to be to allow for better storage. This act allowed us to be reflective of how the physical, digital and auditory aspects of the design were crafted and finalized with the materials at hand and helps us to reflect on new concerns that arise during using it in practice. This methodology resonates in principle with autobiographical or first-person research design [28] which is gaining acceptance within the HCI and TEI community [3,21,30]. To this end, we reflect on our design journey in the form of five themes, namely structure, storage, arrangement, multimodal feedback and assembly that we believe form the core of the multimodal open pantry system and we hope will guide the future development in this space.

THINKING BEHIND FOODCHESTRA

The design of *FoodChestra* is inspired by the current trends of open closets and traditional food storage practices of hanging food in the open. Open closets serve the purpose of *'right there, in sight'* as all the items are on display. Open closets not only serve as a form of self-expression where users can show-off their minimal yet trendy collection, but it also creates a social persuasion on adopting a minimalist lifestyle and attitude. Social persuasion refers to the purposeful attempt to change an individual's attitude or behavior through social influence [7]. We also aimed to make our design playful and inviting to encourage users to interact with it naturally and should not remain purely educational.

We designed *FoodChestra* to hold food items that have a shelf life of a few days and that are amongst the most wasted domestic food such as fruits, bread and vegetables [44]. Hence, the system comes with different types of bags that hold food items based on their shapes. The bags are designed to allow users to be able to observe the changing stages of food and attend to them on time.

For an effective social persuasion, we also aimed to develop a tangible artifact that can be placed anywhere in the household and serve as a conversation pointers on food consumption practices. We draw on earlier works that indicate benefits of tangible systems towards deeper reflection on shared practices [14,16] and for enabling learning through physical manipulation. Finally, we designed *FoodChestra* as a modular system to facilitate easy assembly and disassembly. This is inspired by previous works [12,20,33,37], which suggest that involving users in the making generates curiosity and better learning outcomes and support the pleasures of self-creation, known as the *IKEA* effect [29].

STRUCTURE

Structure is the first key component of an open pantry and it refers to the physical frame, where the food items can be stored.

When creating the structure for *FoodChestra*, the thing that inspired us the most was the ancient Asian and Medieval practice of hanging food items on the roof or walls of the kitchen with ropes and hooks [34]. The intention behind this practice was to increase the visibility of food items in shared households where multiple people were responsible for cooking and shopping the food items. Besides, the hanging practice also prevented the food items from animals, and helped to preserve them for longer by allowing better air flow through woven airy bags. We also see traces of this concept in the current trends of open closets where the clothes are displayed openly to increase their visibility. Drawing on these two practices, we decided to create an open hanging based structure to display food items in the shared living spaces (refer to Figure 4).

During our trials, we tried different shapes for the open structure but finally settled on a minimalistic A-shape design that provides a strong foundation to hold the selected food items without taking much space of its own. Instead of fabricating the frame ourselves, we bought an open closet frame from a furniture store and customized it to fit our purpose. We also went with a wooden frame instead of a metal one to give it a natural look, so that it blends well with the background and stored food items.

However, we realized that simply hanging the food items would neither invite users' attention when needed nor would it provide a direct feedback on their consumption behavior. So we needed to explore mechanisms that would enable easy storage, access and interaction with the food. This resulted in exploring different designs for the storage bags as well as placement of the food on the structure, which we will cover next.

LESSONS LEARNED

When deciding the structure for an open pantry, it is important to understand 1) the space, of which it would be a part of, 2) frequency of interaction and 3) weight and quantity of the items. Designers can also seek inspiration from outside of traditional food storage practices, such as the open closet design. Moreover, instead of treating the structure as a means for storage, make it a form of self-expression that with time could reflect one's lifestyle and could bring gradual change in their food consumption and disposal behaviors.

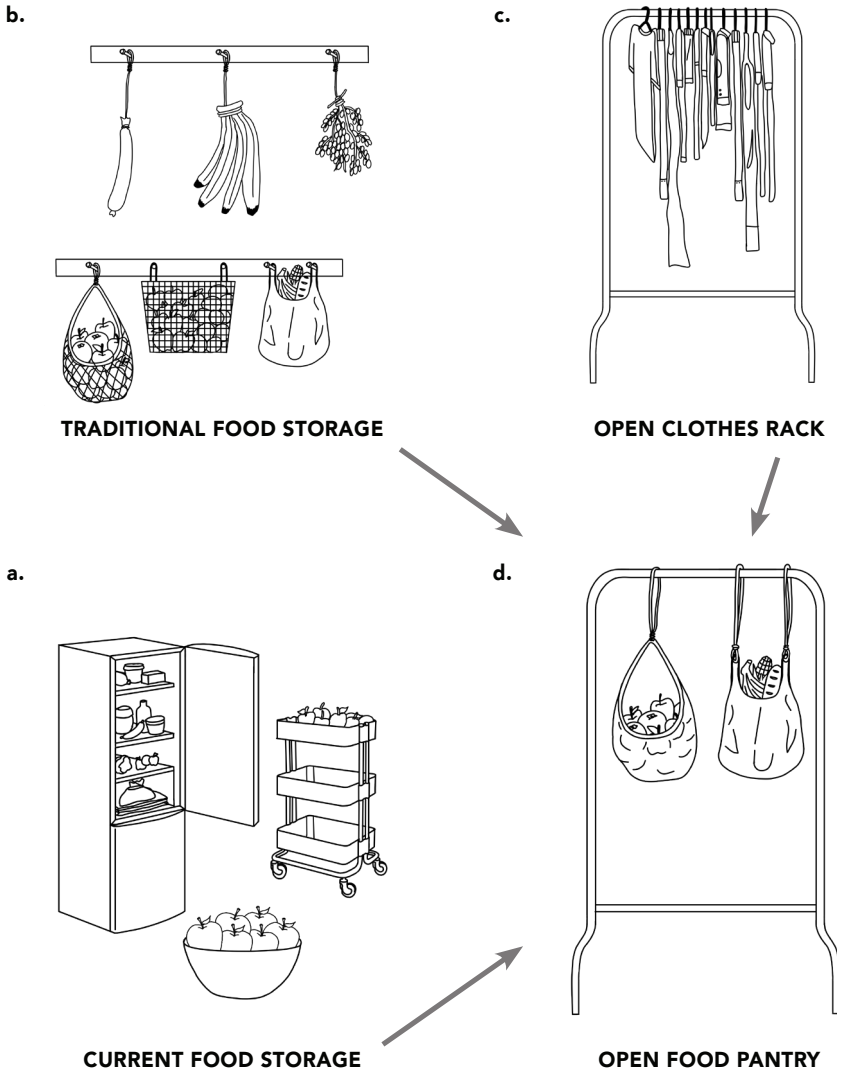

Figure 4: We drew from ancient practices of hanging food and current trends of open closet to create a structure that is not only used to store food in the open but it can also be a part of one's self-expression and demonstrative of one's lifestyle.

STORAGE

Storage is the second key component of an open pantry that refers to the way in which food items are stored on a structure with special attention to their shelf life.

Storing food items require proper handling and consideration on refrigeration and light to maintain their shelf-life. For example, meat and dairy products need refrigeration to keep them fresh, while root vegetables like potatoes need to be placed in the dark to sustain their shelf life.

Initially we did consider adding a refrigeration component to our design using thermoelectric [27] as well as traditional ceramic methods [41], however when we checked the most commonly wasted food items, we realized that these are the foods that do not require refrigeration [45]. Hence we discarded the idea to keep the design simple. The lack of refrigeration also meant that we are not altering the natural shelf life of the food. Figure 5 enlists some of the food items that can be stored in *FoodChestra*. This list includes common fruits and vegetables as well as everyday items such as bread, biscuits, chocolates and snacks.

After deciding on the food items, we focussed our attention on the storage mechanism. While technology exists to slow down the natural cycle of the fresh produce and to keep the food fresh for longer, individuals do not get to witness the natural progression of food like the visual, olfactory and tactile changes that occur to food over time as the food remains hidden inside a refrigerator or closed pantry. Addressing this, we focussed on the design of the storage bags that offer glanceable feedback on the natural progression of food.

We first thought of using transparent plastic bags for food storage, however, we discarded the option as plastic bags can speed up the ripening of certain fresh food. For instance, plastic bags keep the moisture and certain gasses released by food items trapped, which speeds up the ripening. Therefore, we decided to design our own netted bag using cotton ropes and linen cloth as seen in Figure 6-8, which partially cover the food items allowing users to actually see and touch the changing textures of foods.

Figure 5: Common fruits and vegetables as well as everyday items such as break, biscuits, chocolates and snacks that do not require refrigeration can be stored in FoodChestra. Photo by Engin Akyurt on Unsplash

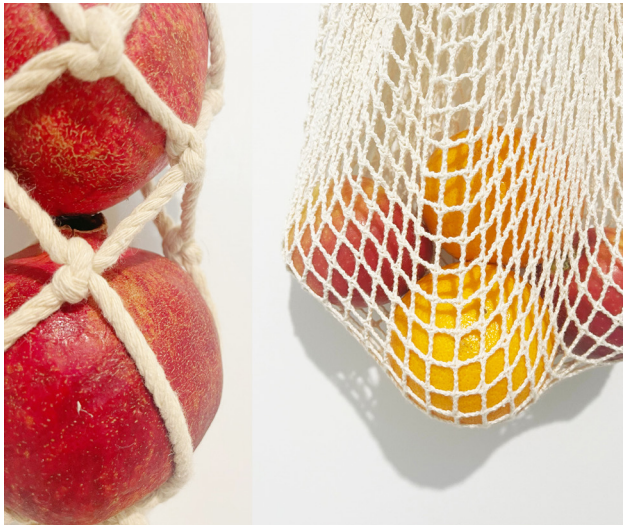

Figure 6: The inspiration for woven storage bags came from traditional baskets weaves commonly used in Ancient cultures to store food.

Figure 7: We explored different materials for creating the storage bags.

Figure 8: We manually woven the storage bags in a macrame style.

Rather than fixing on one specific design for storage bags, we decided to create four categories of bags depending upon the specific characteristics of different food items (see Figure 9). We felt that such categorization could support deeper reflection as users could reflect on the characteristics of food type, reasons behind their wastage and their consumption patterns while storing and consuming the food. These additions of bags happened progressively as the lead authors used the system in her home and realized the need for storing different foods differently.

The first bag category is *"Pieces A & B"* that allows storing round hard skin food items without being squashed, for example, apples and oranges. These bags are designed with special knots that have some spacing in between to reveal the texture of the fresh produce. Moreover, we made these bags stretchable by carefully weaving the knots. This allows us to accommodate food items of varying size like small lemons and big oranges.

The second bag category is *"Length A & B"*, which allows storing of lengthy food items like breads, bottle gourds, celery and carrots. Length A bag provides an additional feature of adjusting its length depending upon the item stored. We thought that adjusting the length of the bag is essential to support glanceable feedback on the consumption of items like breads that may not be consumed at one time. As a result, users can adjust the length of the bags based on the consumption.

The third category of bags is *"Stack A & B"*. These bags are designed to store fresh produce that have a soft texture and can easily get squashed if not handled properly. For instance, fruits like grapes, strawberries, tomatoes and bananas are easier to get bruised and once bruised, they also tend to rot faster. To avoid this issue, we made Stack A as a breathable bag made of linen, which acts like a cushion for fragile fruits like strawberries. On the other hand, a Stack B bag consists of a tray where fruits like grapes can be stored.

The fourth and final category is *"Mesh A & B"*, which are designed to store food items that are half finished, but need to be attended on time. For instance, chocolates, chips and cookies stay fresh only for a couple of days after opening, and need to be consumed on time to maintain freshness and flavor or else they could get soggy and dull. We made Mesh A & B bags of different sizes to accommodate items of different sizes. These bags are made of cotton net and are flexible in storring all kinds of half-opened packaged food items.

LESSONS LEARNED

While designing storage for an open pantry, it is important to decide on refrigeration and select food items accordingly. Consider revealing and not concealing the natural texture, color, smell, and taste of food during storing to facilitate a more tangible learning experience and to aid users in connecting with their food and its shelf life. Provide users with different storage options to allow for creative storing decisions and for bringing more attention to the food. Consider the specific characteristics of food items to design storage bags. Also, pay attention to choice of material for the bags that should not interfere with the natural progression of the fresh produce.

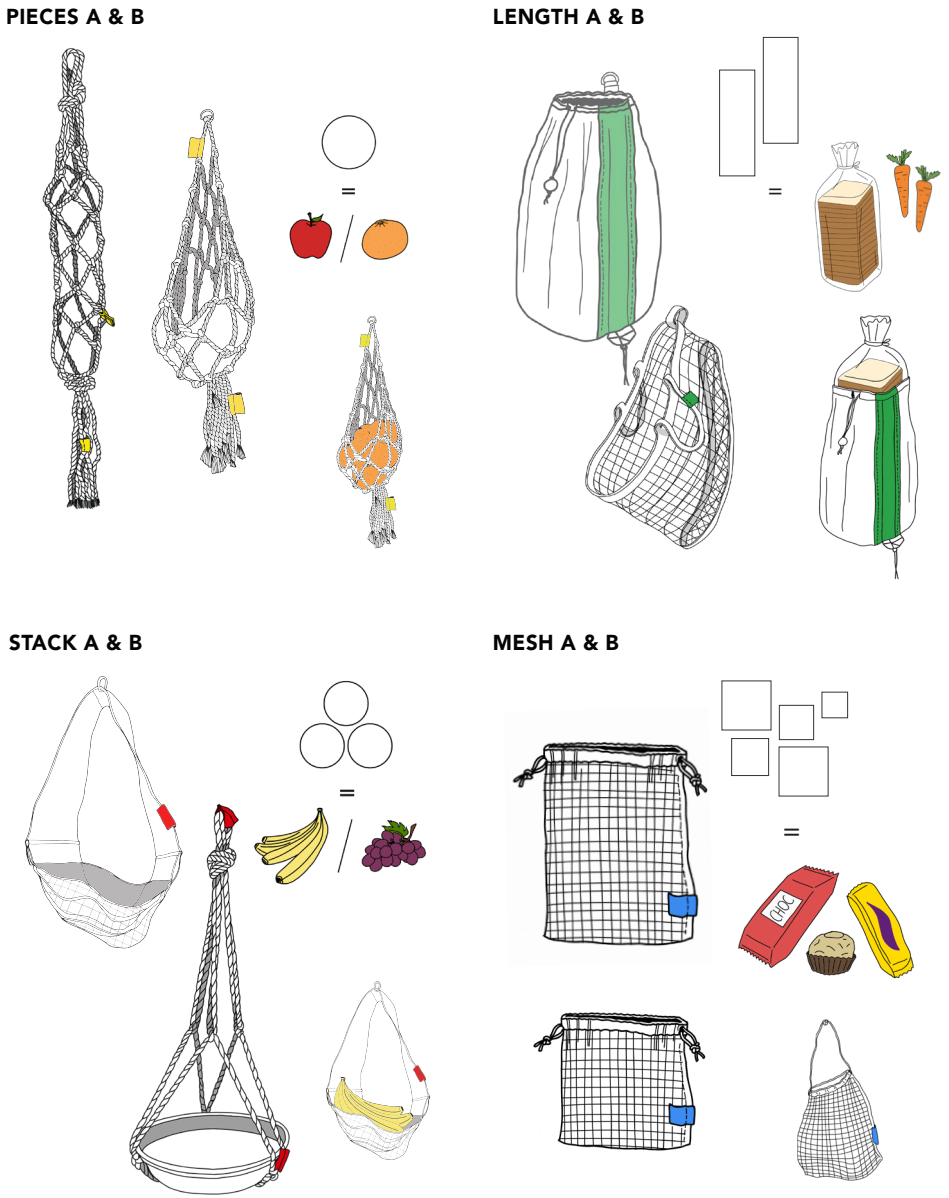

Figure 9: We designed four kinds of bags to store different food items based on their unique characteristic and storing method.

ARRANGEMENT

The third key component of the open pantry design is Arrangement, which refers to positioning or placement of storage items on the structure to offer visual feedback on consumption.

Taking inspiration from both ancient storing methods of food hanging and the current trends of an open closet for hanging cloths, we decided to have the bags of food hung on the open structure using ropes and hooks. However, we later realized that such an arrangement was too static and offered limited feedback on food in terms of its progression and on its consumption.

To overcome this, we incorporated the simple pulley mechanism into our design and created an arrangement that involves suspending a rope over a fixed pulley and attaching a food storage bag and a weight bag on either side of the rope (see Figure 10). In a simple pulley mechanism, when the rope is pulled, the pulley rotates, which will then change the position of the weight bags that are hanging on the other side of the rope. As a result, the position of the weight bags and food items will gradually change when food gets consumed and when users interact with the system to take food out. For example, each time food is removed from a bag of food, it reduces the load weight causing the bag to be hung relatively higher than before. This constant interaction with the food will influence the way the food bags are positioned relative to the other food bags, thus resulting in food that was consumed more hanging at a higher position while food that was neglected remains at a lower hanging position. This process will allow users to witness changes to their consumption patterns by observing the visual change of the food position on the rope in relation to other food items stored on *FoodChestra* as seen in Figure 13. We envision that over time, through such an arrangement, users will become knowledgeable about the weight and quantity of different foods, which in turn would help them understand and reflect on their consumption pattern.

We made the weight bags out of linen and cotton material that are customizable depending upon the weight of the item stored in the bag. Each bag can store up to 5kgs of weight. The weight bags can be filled with items like rice, pebbles and small rocks, which are easy to find in and around a household. We settled on 5 kg by trialing different weights while studying its use at home with different foods. For the smooth functioning of the pulley mechanism, we tested a variety of ropes such as hemp and cotton as well as single braided and multi-braided varieties that could hold the bags of varying weights (see Figure 11) and finally selected the multi-braided cotton rope option.

Finally to enable the knocking mechanism, when *FoodChestra* is not attended for some time, we added an ultrasonic sensor underneath each bag that can detect the position of the bag and then trigger knocking after long non-use as seen in Figure 12. We discuss the knocking system in more detail under the theme of Multimodal feedback.

LESSONS LEARNED

When deciding on the food arrangement, focus on layouts, visual cues and movement to offer subtle visual feedback on food consumption.

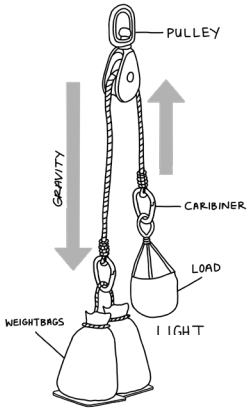

Figure 10: We added a pulley mechanism to *FoodChestra* to enable visual feedback on food consumption. Whenever users interact with the system to store or take the food out, the position of the food item will change.

Rope A : 3mm / Cotton single braided rope / Thin and weak when weights are placed on the rope in the pulley.

Rope B : 6 mm / Cotton single braided rope / Correct thickness but still relatively soft to hold weights.

Rope C : 3 mm / Twine single braided / Brittle and thin causing the rope to slight within the pulley.

Rope D : 6 mm / Cotton Rope multi braided / Sturdy and perfect fit for the pulley with weights and food loads. [CHOSEN]

Figure 11: We tried different ropes and tested their strength to hold different food items. Finally we chose a 6mm multi-braided cotton rope.

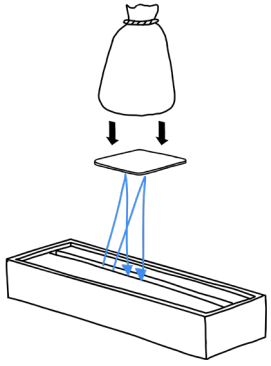

Figure 12: We added an ultrasonic sensor underneath each weight bag to detect the change in its position after user interaction.

MULTIMODAL FEEDBACK

The fourth key component on an open pantry is Multimodal feedback, which is added to the design to serve as a social nudge for users to engage with the system.

Hermsen and colleagues highlight the effectiveness of the feedback when it is offered using more than one modalities [13]. Drawing on this, we decided to offer multimodal feedback, consisting of visual, tactile, olfactory and auditory modality on individuals' food consumption. The visual feedback is offered through the pulley mechanism and selection of storage bags as discussed in the previous theme of *Arrangement* (refer to Figure 13) while the tactile and olfactory feedback is offered through the open netted design of storage bags that enable users to see, smell and feel the texture of foods stored in *FoodChestra*. To complement these two modalities and to nudge users to interact with the system, we also added two kinds of auditory feedback: interaction feedback and reminder feedback. Let us discuss them one by one.

Interaction Feedback: The first kind of auditory feedback is about users' interaction with the system. Drawing on cow bell style design we added small bell rings on each rope. These bells ring whenever the user touches or interacts with the rope. Before moving to the bells, we did think of a digital sound notification system on a mobile or a desktop. However, we discarded this option as it felt as detached from the system. We instead opted for a physical method, where each time a user interacts with the system, the attached bell will ring, signaling to others that someone is using the system. In this way, it would create a social nudge for others to also interact with the system (see Figure 14).

Reminder feedback: The second kind of auditory feedback is reminder feedback that nudges users to interact with *FoodChestra*. Similar to traditional food storing practices, the purpose of displaying and hanging food items out in the open is to prolong the shelf life of food but also allow more attention to the progression and maturity of the food produce to prevent unnecessary food waste. We achieve this through an automated knocking system to remind users to engage with the system in a timely manner.

We added an ultrasonic sensor at the bottom of each weighted bag to measure the position of the bags. A timer is then started and records how long the weighted bags were at the same position. If any one of the weighted bags remain at the same position for 24 hours, it means that the user has not interacted with the system so the system will then trigger the knocking sound using the solenoid. The knocking will happen for 5 seconds every 15 minutes until a user interacts with the system. We identified this duration through repeated trials and use at home. Besides, the interval of 24 hours is set to encourage users to attend *FoodChestra* at least once per day. Figure 15 shows the schematic of the knocking system.

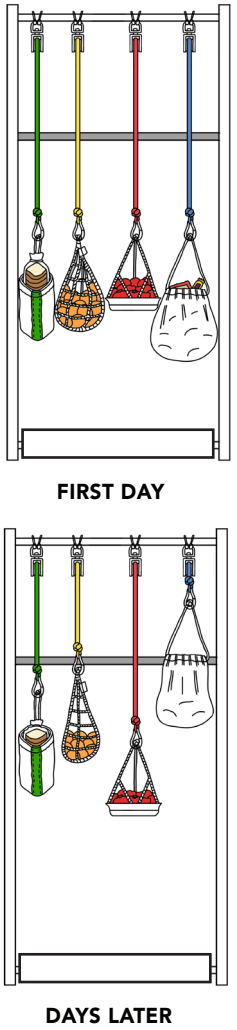

Figure 13: The height of the storage bags change as the food gets consumed over time, thus providing visual feedback on the food consumption, like a distant physical bar chart illustrating the food consumption pattern over time like which foods they eat most and which foods need their attention.

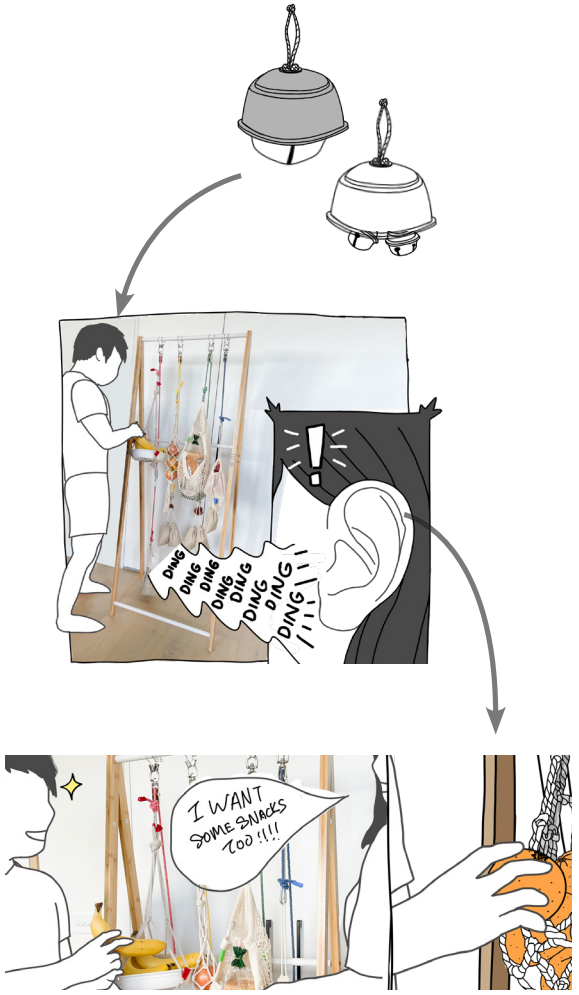

Figure 14: Each time any user interacts with the FoodChestra system, the attached bell will ring, signaling to other co-located users that someone is currently using *FoodChestra* and it may prompt them to interact with the system too.

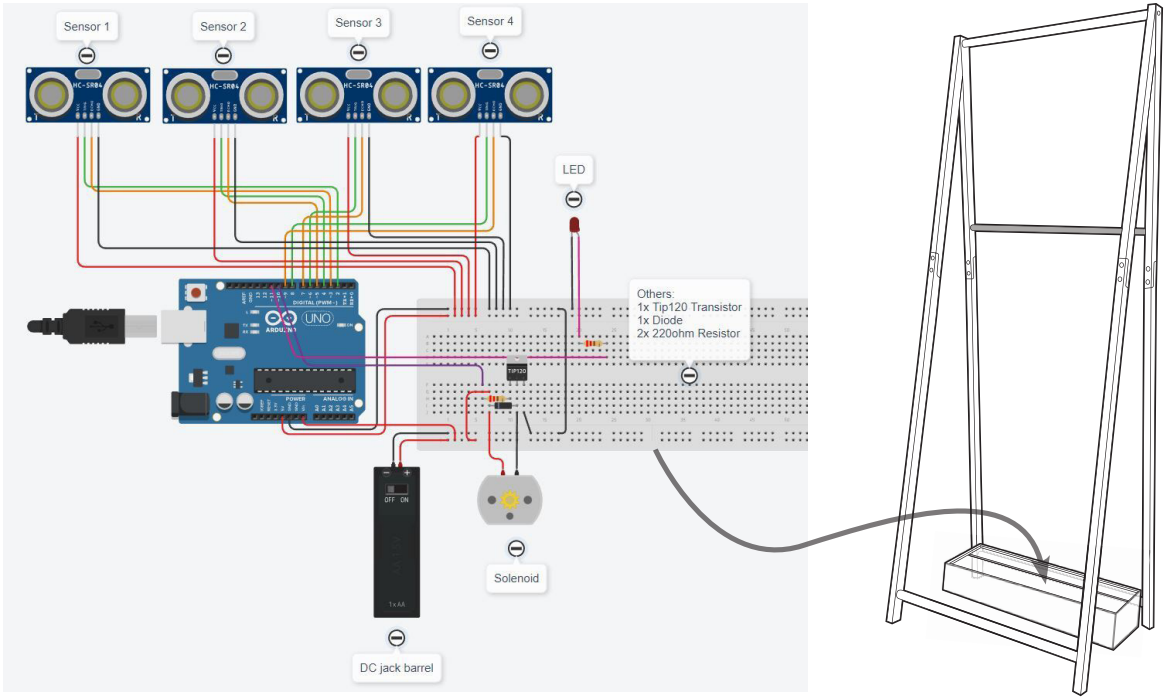

Figure 15: The schematic view of how the automated knocking system works

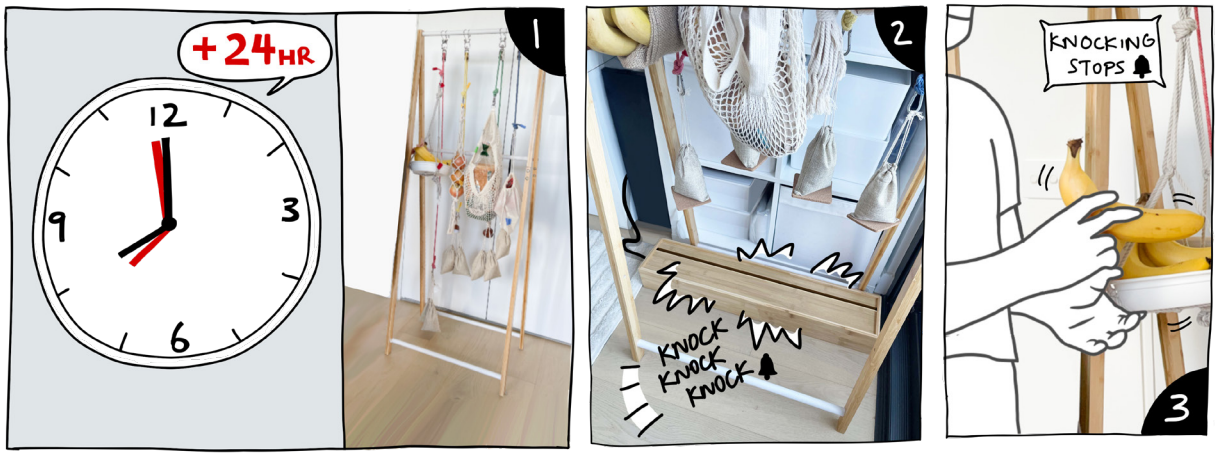

Figure 16: Scenario of knocking system being triggered, after food is left unattended for 24 hour

To enable our system to detect the position of the weight bags, we modified the weight bags with a cork material at the base (See Figure 12). This is to provide a hard surface for the ultrasonic sensor to detect the position of the weight bags as a clothes material may interfere with how ultrasonic waves are bounced off which may lead to inaccurate position readings. Therefore, to compensate for that, we sew on a rectangular cork material at the base of each weight bag, providing a hard surface for the ultrasonic sensor to detect accurately.

We designed the knocking sound by having a solenoid knocking onto a metallic profile creating a subtle yet profound clicking sound. We want to make sure that the sound was not too aggressive to prevent annoyance. We also note here that each of the ultrasonic sensors detecting the weighted bags is connected to one solenoid and it was an intentional design decision to keep the prompt anonymous. As such, the knocking system does not detect specific food that needs prompt attention and rather it simply notifies the users to explore *FoodChestra* on their own to identify which food needs their attention. The knocking system works similar to a knock on the door, when we don't know the reason behind the knocking until we open the door. This creates a playful interaction and opportunity for users to pay attention and have a deeper reflection on their consumption patterns (see Figure 16).

LESSONS LEARNED

Explore both digital and analog methods for creating effective multimodal feedback on user interactions. Using auditory feedback such as bell rings can allow even bystanders to notice the interactions and they could nudge individuals to take an action. Focus on subtly and offer users the agency to control the audio feedback as needed.

ASSEMBLY

The final component of an open pantry is assembly, which describes the modular design of the entire system, allowing users to easily assemble and/or dissemble pieces together as well as manage its placement in the users' home.

In order to make *FoodChestra* a part of someones' home, we focussed on three things: minimalism, easy assembly and placement. We developed a modular design for *FoodChestra*, which can be easily flat-packed in a bag as shown in (see Figure 17). Following the DIY style of the commercial furniture setup such as *IKEA*, the *FoodChestra* bag consists of a manual to guide the user for easy assembly and disassembly. Being lightweight, users can assemble it on their own and move it around the house based on their needs. The structure is designed such that it can hold the food safely and securely. The size of the *FoodChestra* pantry is in line with a basic open-style clothing rack thus occupying minimal space. Users can also alter the number of ropes, add or delete any part of the system to suit their space requirements.

In terms of placement of the open pantry in the house, we considered a variety of spots such as the dining area, kitchen, and living room. However, after using *FoodChestra* at home, we feel that the recommended placement would be a living-dining room as a direct visual proximity to *FoodChestra*, which would allow users to attend to food easier when needed (see Figure 1 and 18).

FoodChestra features a minimalistic design with neutral color schemes and natural materials to keep it sustainable. The packaging design of *FoodChestra* is simple and comes with a well documented user manual (refer Appendix). It encourages users to be creative in their setup while accommodating the food storage needs of different types of users.

Figure 18: A simulated image to show the placement of FoodChestra in a physical context.

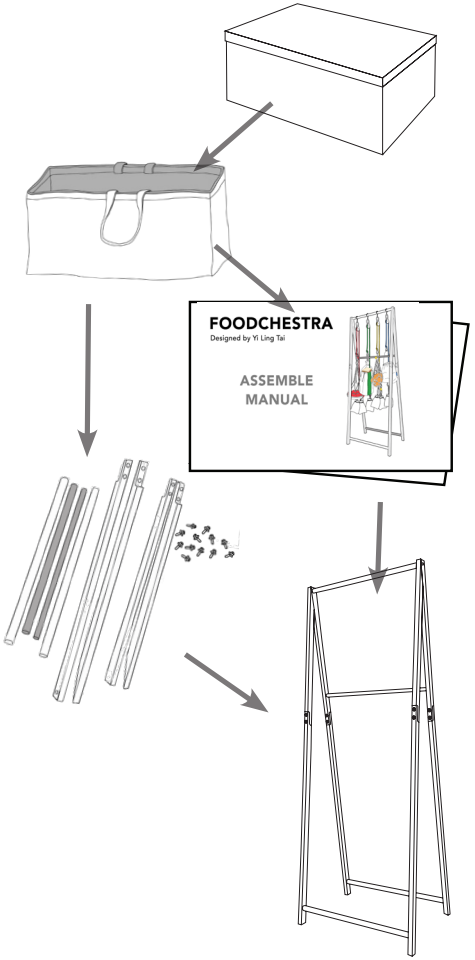

Figure 17: *FoodChestra* comes with a *IKEA* style user's manual and flat pack design.

LESSONS LEARNED

Allowing users in the assembly process will generate curiosity and support for IKEA self-creation effect [29]. Focus on minimalism and allow modifications to suit spatial requirements of different households.

REFLECTIONS AND CONCLUDING REMARKS

Issues of domestic food waste and disposal are complex as the cause and effect are not directly visible to the general audience [35,36]. They require effective motivational strategies to engage individuals to reflect on their food practices first and the change in their behavior may happen gradually over time. For instance, in early stages of change, users may require strategies that can help them in overcoming reluctance or inadequate motivation through gradual increase in their awareness about themselves and their food related behaviors. Over time, individuals can then re-evaluate their activities and take necessary action [22]. *FoodChestra* is a step towards this direction to enable gradual change in behavior through a domestic open display of one's food storage and consumption.

FoodChestra is the first furniture-based design solution that offers a playful approach to tackle the problem of food waste. *FoodChestra* offers multimodal feedback through its intelligent design and invites users to attend to the food in a timely manner. Given the current lifestyle trends of openly displaying one's lifestyle, values and personality through the interior design, open closets and island kitchen [11], we envision *FoodChestra* becoming another style statement in urban households. Our next step is to conduct a field study of *FoodChestra* with shared households to understand whether and how it creates reflection on one's food consumption and food waste practices. We conclude the paper by describing two design considerations that can assist designers in making creative open food pantry solutions.

Design for tinkering: *FoodChestra* features a minimalistic design and affords similar appropriations that are possible with any household furniture and it invites user participation at different levels. It follows a DIY style assembly, where users are required to make different decisions as they set it up for their household needs. For instance, users need to decide the color of the ropes, the style of the storage bags as per their food items, the combination of bells they want, the weight of the pulley bags, and the placement of the system. These decisions need to be revisited with time as they understand the shelf-life of different food items as well as their food practices. Users can also appropriate the *FoodChestra* system based on their health goals. For example, they can associate meanings to different coloured ropes to remind themselves to eat healthy. The accompanying assembly manual describes a few possible customization options to guide and inspire the users.

Researchers suggest that people feel the need to transform their living spaces and make them an extension of their personality by exhibiting their personal tastes and values [11]. Being able to transform *FoodChestra* is an important feature because it gives agency to the users to take control of their surroundings. Also, the more appropriations we make, the more connected we feel with the artifact [10,24]. In doing so, *FoodChestra* creates a design space that encourages users to tinker with the system to suit their food storage needs, while gradually raising awareness about their food consumption behaviors. This increased awareness might help them to rethink their food shopping and disposal practices over time. This supports the concept of *IKEA* effect, which says that when consumers self-create a product, they appreciate it to a greater degree [29]. Drawing on this, we suggest designers and TEI researchers to include tinkering options within their design to facilitate engagement.

Design for subtly: Miller argues that physical things have the tendency to disappear in the background, and they come to one's attention only when their needs arise, which he refers to as *"Humility of Things"* [26]. Drawing on this, we paid special attention to keep the interaction and feedback subtle and not attention-grabbing.

FoodChestra uses natural materials like bamboo and linen with neutral colors that can easily merge with the background when not in use. There are no visible exposed electronic components nor any flashy lights demanding users' attention. Instead, *FoodChestra* makes use of pulley based mechanisms to create an intelligent visual dashboard of one's food consumption pattern over time. As users start filling and subsequently consuming food products from *FoodChestra*, they would visually witness a progression in their food consumption behavior. Users can further tinker around with the weight of the pulley bags to get the more evident visual feedback, for instance, using heavier weight bags over the pulley will allow the storage bag to move up drastically with every food intake.

We used the variance of familiar sounds such as cow ring bells and knocking sounds to subtly nudge users about their interaction with the system. The pleasant sound of cow bell ringing indicates an active interaction whereas the dry mechanical sound of knocking reminds users that someone needs their attention. The automated knocking sound system would also become quieter with more frequent interactions with the system. We note here that these knocking reminders are not meant as a 'nudge' to eat, rather it reminds people to pay attention to the displayed food such as their shelf life, their availability etc. Users are not required to eat every time they get a reminder, rather it is mainly to create awareness about what food items they already have, so that they can plan their consumption or shopping accordingly. The system does not aim to encourage or ask users to adopt any new eating habits, rather we are providing them opportunities to reflect on their existing habits and change them based upon their preference. Secondly the knocking system or the reminder feedback is an optional component of *FoodChestra* design. Once users understand their consumption pattern and do not feel the need to be reminded, they could turn this feature off. The system would still work as usual offering users the visual, tactile and auditory feedback through its design and the bell rings.

Besides system led feedback, *FoodChestra* also taps into social persuasion to motivate members of a shared household to understand each other's food consumption pattern, through the physicality of the system and chosen nature of feedback. The open pantry design means that the one's consumption pattern is noticeable to everyone, not just the person who is interacting with the system. Whenever someone interacts with the system, there is a subtle auditory feedback in terms of cow-bell rings and when the interaction ends, there is visible trail of interactions in terms of altered heights of food bags. Through such interactions, household members can observe which foods are getting consumed the most and which are not (hence thrown away) and could nudge each other towards better food practices. Interestingly, all these interactions do not have to be immediate one after another, rather it can be spread across time. For example, a users' interaction with the system (i.e., the visible trail of altered height of the bags) will remain visible until any new interaction happens with the system. So other bystanders can still see the interaction in the afternoon or night. This enables an asynchronous mode of feedback wherein nudging and social persuasion could happen over time. The follow up field study would unveil more insights on this topic but we encourage researchers to consider such subtle asynchronous modes of feedback and interaction in their design to facilitate social persuasion.

Finally, *FoodChestra* aims to reconnect with food through celebrating the physicality and aesthetic of food itself. For instance, the multisensorial properties of the food items such as the change in texture, smell and visuals are visible through the 'naked' bags. The 'naked' bags support glanceable feedback [9] of the food items from a distance and invites the user's attention to the food when needed, through its multisensory signals. With *FoodChestra*, we opened a new design space and we hope it inspires HCI and TEI researchers to rethink the kitchen space for everyday reflection on our food practices and to adopt new creative and subtle ways of creating multimodal feedback.

REFERENCES

[1] Ferran Altarriba, Stefano Eugenio Lanzani, Ana Torralba, and Mathias Funk. 2017. The Grumpy Bin: Reducing Food Waste Through Playful Social Interactions. *In Proceedings of the 2017 ACM Conference Companion Publication on Designing Interactive Systems (DIS '17 Companion),* 90–94. https://doi.org/10.1145/3064857.3079125

[2] Rima Sabina Aouf. 2018. Tupperware-style products use the Internet of Things to help you reduce your food waste. *Dezeen.* Retrieved August 6, 2022 from https://www.dezeen.com/2018/05/29/smarterware-ovie-smart-tupperware-internet-of-things-food-waste/

[3] Karen Cochrane, Yidan Cao, Audrey Girouard, and Lian Loke. 2022. Breathing Scarf: Using a First-Person Research Method to Design a Wearable for Emotional Regulation. *In Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '22),* 1–19. https://doi.org/10.1145/3490149.3501330

[4] Jennifer Michelle Domareki. 2018. Out of sight, out of mind: An analysis of household food waste in Arcata, California. Retrieved October 16, 2022 from https://digitalcommons.humboldt.edu/etd/199/

[5] Geremy Farr-Wharton, Marcus Foth, and Jaz Hee-Jeong Choi. 2012. Colour coding the fridge to reduce food waste. *In Proceedings of the 24th Australian Computer-Human Interaction Conference (OzCHI '12),* 119–122. https://doi.org/10.1145/2414536.2414556

[6] Geremy Farr-Wharton, Marcus Foth, and Jaz Hee-Jeong Choi. 2013. EatChaFood: challenging technology design to slice food waste production. *In Proceedings of the 2013 ACM conference on Pervasive and ubiquitous computing adjunct publication (UbiComp '13 Adjunct),* 559–562. https://doi.org/10.1145/2494091.2497311

[7] B. J. Fogg. 2002. Motivating, influencing, and persuading users. *In The human-computer interaction handbook: fundamentals, evolving technologies and emerging applications.* L. Erlbaum Associates Inc., USA, 358–370.

[8] William Gaver. 2012. What should we expect from research through design? *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12),* 937–946. https://doi.org/10.1145/2207676.2208538

[9] Rúben Gouveia, Fábio Pereira, Evangelos Karapanos, Sean A. Munson, and Marc Hassenzahl. 2016. Exploring the design space of glanceable feedback for physical activity trackers. *In Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '16),* 144–155. https://doi.org/10.1145/2971648.2971754

[10] Marc Hassenzahl. 2018. The Thing and I: Understanding the Relationship Between User and Product. *In Funology 2: From Usability to Enjoyment, Mark Blythe and Andrew Monk (eds.).* Springer International Publishing, Cham, 301–313. https://doi.org/10.1007/978-3-319-68213-6_19

[11] Carolyn S. Hayles. 2015. Environmentally sustainable interior design: A snapshot of current supply of and demand for green, sustainable or Fair Trade products for interior design practice. *International Journal of Sustainable Built Environment 4,* 1: 100–108. https://doi.org/10.1016/j.ijsbe.2015.03.006

[12] Bart Hengeveld, Caroline Hummels, Kees Overbeeke, Riny Voort, Hans van Balkom, and Jan de Moor. 2009. Tangibles for toddlers learning language. *In Proceedings of the 3rd International Conference on Tangible and Embedded Interaction (TEI '09),* 161–168. https://doi.org/10.1145/1517664.1517702

[13] Sander Hermsen, Jeana Frost, Reint Jan Renes, and Peter Kerkhof. 2016. Using feedback through digital technology to disrupt and change habitual behavior: A critical review of current literature. *Computers in human behavior 57*: 61–74. https://doi.org/10.1016/j.chb.2015.12.023

[14] Eva Hornecker and Jacob Buur. 2006. Getting a grip on tangible interaction: a framework on physical space and social interaction. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '06),* 437–446. https://doi.org/10.1145/1124772.1124838

[15] Christopher D. Ives, David J. Abson, Henrik von Wehrden, Christian Dorninger, Kathleen Klaniecki, and Joern Fischer. 2018. Reconnecting with nature for sustainability. *Sustainability Science 13,* 5: 1389–1397. https://doi.org/10.1007/s11625-018-0542-9

[16] Rohit Ashok Khot, Larissa Hjorth, and Florian Mueller. 2020. Shelfie: A Framework for Designing Material Representations of Physical Activity Data. ACM Trans. *Comput.-Hum. Interact.* 27, 3: 1–52. https://doi.org/10.1145/3379539

[17] Rohit Ashok Khot and Florian Mueller. 2019. Human-Food Interaction. *Foundations and Trends® in Human–Computer Interaction 12,* 4: 238–415. https://doi.org/10.1561/1100000074

[18] Ilpo Koskinen, John Zimmerman, Thomas Binder, Johan Redstrom, and Stephan Wensveen. 2011. *Design Research Through Practice: From the Lab, Field, and Showroom. Elsevier.*

[19] Angus Laing. 2019. Food Waste Facts. *Foodbank.* Retrieved January 21, 2022 from https://www.foodbank.org.au/food-waste-facts-in-

australia/?state=vic

[20] Mannu Lambrichts, Jose Maria Tijerina, and Raf Ramakers. 2020. SoftMod: A Soft Modular Plug-and-Play Kit for Prototyping Electronic Systems. *In Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '20),* 287–298. https://doi.org/10.1145/3374920.3374950

[21] Andrés Lucero, Audrey Desjardins, Carman Neustaedter, Kristina Höök, Marc Hassenzahl, and Marta E. Cecchinato. 2019. A Sample of One: First-Person Research Methods in HCI. *In Companion Publication of the 2019 on Designing Interactive Systems Conference 2019 Companion (DIS '19 Companion),* 385–388. https://doi.org/10.1145/3301019.3319996

[22] Gregory R. Maio, Geoffrey Haddock, and Bas Verplanken. 2018. *The Psychology of Attitudes and Attitude Change.* SAGE.

[23] Alexander Marc Mantel and Michael Prilla. 2019. *SmartFooding: Input and Tracking of the Shelf Life of Groceries to Reduce Food Waste.* 707–711. https://doi.org/10.1145/3340764.3344895

[24] Sampada Marathe and S. Shyam Sundar. 2011. What drives customization? control or identity? *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11),* 781–790. https://doi.org/10.1145/1978942.1979056

[25] Natalie Marchant. 2021. Global food waste twice the size of previous estimates. *World Economic Forum.* Retrieved August 6, 2022 from https://www.weforum.org/agenda/2021/03/global-food-waste-solutions/

[26] Daniel Miller. 2010. *Stuff.* Polity.

[27] More About Opengreenenergy ». 2016. DIY Portable Mini Refrigerator. *Instructables.* Retrieved October 20, 2022 from https://www.instructables.com/DIY-Portable-Mini-Refrigerator/

[28] Carman Neustaedter and Phoebe Sengers. 2012. Autobiographical design in HCI research: designing and learning through use-it-yourself. *In Proceedings of the Designing Interactive Systems Conference (DIS '12),* 514–523. https://doi.org/10.1145/2317956.2318034

[29] Michael I. Norton, Daniel Mochon, and Dan Ariely. 2012. The IKEA effect: When labor leads to love. *Journal of consumer psychology: the official journal of the Society for Consumer Psychology 22,* 3: 453–460. https://doi.org/10.1016/j.jcps.2011.08.002

[30] Claudia Núñez-Pacheco. 2022. Dialoguing with Tangible Traces: A Method to Elicit Autoethnographic Narratives. *In Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '22),* 1–14. https://doi.org/10.1145/3490149.3502255

[31] Doenja Oogjes, Miguel Bruns, and Ron Wakkary. 2016. Lyssna: A Design Fiction to Reframe Food Waste. *In Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems (DIS '16 Companion),* 109–112. https://doi.org/10.1145/2908805.2909401

[32] Jeda Palmer. 2020. The pros and cons of emerging technology in our food system. *Food Systems and Global Change.* Retrieved August 6, 2022 from https://research.csiro.au/foodglobalsecurity/the-pros-and-cons-of-emerging-technology-in-our-food-system/

[33] Nicolas Rasamimanana, Frederic Bevilacqua, Norbert Schnell, Fabrice Guedy, Emmanuel Flety, Come Maestracci, Bruno Zamborlin, Jean-Louis Frechin, and Uros Petrevski. 2010. Modular musical objects towards embodied control of digital music. *In Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction (TEI '11),* 9–12. https://doi.org/10.1145/1935701.1935704

[34] Melissa Snell. 2009. Medieval Food Preservation. *ThoughtCo.* Retrieved August 6, 2022 from https://www.thoughtco.com/medieval-food-preservation-1788842

[35] Yi Ling (ellie) Tai, Deepti Aggarwal, and Rohit Ashok Khot. 2020. Reconnecting with Food through Dining Play. *In Proceedings of the Annual Symposium on Computer-Human Interaction in Play. Association for Computing Machinery,* 334–348. https://doi.org/10.1145/3410404.3414231

[36] Anja Thieme, Rob Comber, Julia Miebach, Jack Weeden, Nicole Kraemer, Shaun Lawson, and Patrick Olivier. 2012. "We've bin watching you": designing for reflection and social persuasion to promote sustainable lifestyles. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12),* 2337–2346. https://doi.org/10.1145/2207676.2208394

[37] Meng Wang, Kehua Lei, Zhichun Li, Haipeng Mi, and Yingqing Xu. 2018. TwistBlocks: Pluggable and Twistable Modular TUI for Armature Interaction in 3D Design. *In Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '18),* 19–26. https://doi.org/10.1145/3173225.3173231

[38] Woollaston. End of the best before date? Food label made from gelatine becomes bumpy when meat is no longer safe to eat. *Daily mail.* Retrieved from https://www.dailymail.co.uk/sciencetech/article-2710689/End-best-date-Food-label-gelatine-bumpy-meat-no-longer-safe-eat.html

[39] Fulya Yalvaç, Veranika Lim, Jun Hu, Mathias Funk, and Matthias Rauterberg. 2014. Social recipe recommendation to reduce food waste. *In CHI '14 Extended Abstracts on Human Factors in Computing Systems (CHI EA '14),* 2431–2436. https://doi.org/10.1145/2559206.2581226

[40] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research Through Design As a Method for Interaction Design Research in HCI. *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07),* 493–502. https://doi.org/10.1145/1240624.1240704

[41] 2007. How to Make a Pot in a Pot Refrigerator. *wikiHow.* Retrieved October 20, 2022 from https://www.wikihow.com/Make-a-Pot-in-a-Pot-Refrigerator

[42] 2020. Food Waste Facts and Hunger Facts. Retrieved December 7, 2021 from https://www.ozharvest.org/food-waste-facts/

[43] Winnow. Retrieved July 14, 2022 from https://www.winnowsolutions.com/

[44] Food Waste Australian Household Attitudes and Behaviours National Benchmarking Study. Retrieved from https://fightfoodwastecrc.com.au/wp-content/uploads/2019/11/Summary-Report_final.pdf

[45] Fight Food Waste CRC. Retrieved August 6, 2022 from https://fightfoodwastecrc.com.au/