# How sustainable is your menu? Designing and assessing an interactive artefact to support chefs' sustainable recipe-planning practices

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## ABSTRACT

Rising sustainability concerns in the food industry have driven the need for innovative approaches in culinary operations. Redesigning the menus and recipes from a sustainability perspective is a promising approach to reducing restaurants' environmental impact. Chefs, as crucial decision-makers in menu and recipe planning practices, play a vital role in promoting sustainable food services. However, the literature lacks insights into chefs' sustainable recipe planning practices and how information and communication technologies (ICTs) could support these practices. This paper addresses this gap by conducting individual interview sessions (n=10) and recipe generation workshops (n=10) with 20 chefs in total. It reveals four dimensions of sustainable recipes (locality, seasonality, frugality, and food quality) based on semi-structured interviews. It presents a novel interactive recipe planning concept called KNOBIE, which was designed to support chefs' sustainable recipe planning practices by using insights that gathered from the interviews. Lastly, based on an assessment of this concept through online recipe generation sessions with chefs, it provides five design implications for integrating ICTs into the sustainable menu and recipe planning practices to promote sustainable food services in restaurants.

## CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Interaction design; Empirical studies in interaction design.

## KEYWORDS

Menu planning, sustainable recipe, design for sustainability, design research, chefs, foodservice industry

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## 1 INTRODUCTION

Sustainability concerns are gaining prominence in the hospitality industry [26]. This industry has been undertaking various efforts to address all 17 SDGs in some ways [23]. One of these efforts is promoting sustainable practices in food services [9, 54, 65], for example, planning the menu [20], preparing and cooking dishes [21], storing food [37], and managing inventory [44] to reduce food waste.

This paper focuses on the menu and recipe planning among the many food service practices that can contribute to sustainability. Menu and recipe planning not only help reduce food waste (e.g., making a sauce from vegetable leftovers) [7, 21, 58] but also help with determining the equipment, ingredients, purchasing procedures, and expenses [32], thus have an impact on a restaurants ecological footprint. Although the importance of sustainability concerns in menu and recipe planning has been recognized in the literature [36, 49, 60], the studies on how to achieve this goal was very few [5, 25]. Furthermore, aside from "sustainable" recipes that can be found on the internet and the grey literature (e.g., WWF [64], NYTimes [45]), the literature lacks studies on how and to what extent restaurant chefs integrate sustainability concerns into their recipe and menu planning practices.

Information and communication technologies (ICTs) have significantly affected how people communicate, interact, and conduct business, including hospitality. The food services industry has recognized the potential of ICTs to promote sustainable practices [13]. For instance, these technologies are utilized to monitor and manage resource consumption (such as water, energy, and food) and improve inventory management [33]. By leveraging ICTs, food service stakeholders can monitor real-time consumption data, enabling them to adjust their practices, optimize efficiency, and save costs. An example of this is Kitro, an automated food waste measurement and monitoring system that helps prevent unnecessary food waste by collecting long-term data [37]. Moreover, ICTs can also be employed in recipe and menu planning practices. For example, inventory management software (e.g., Posist [51]) can help restaurant managers or chefs to record and quantify the materials coming into the restaurant, associated costs, and waste produced because of kitchen operations.

Although there are studies that explore ICTs within the contexts of sustainable kitchen operations and menu planning separately, the literature lacks studies bridging these two topics. On the one hand, previous work in this area has explored using ICTs to mitigate

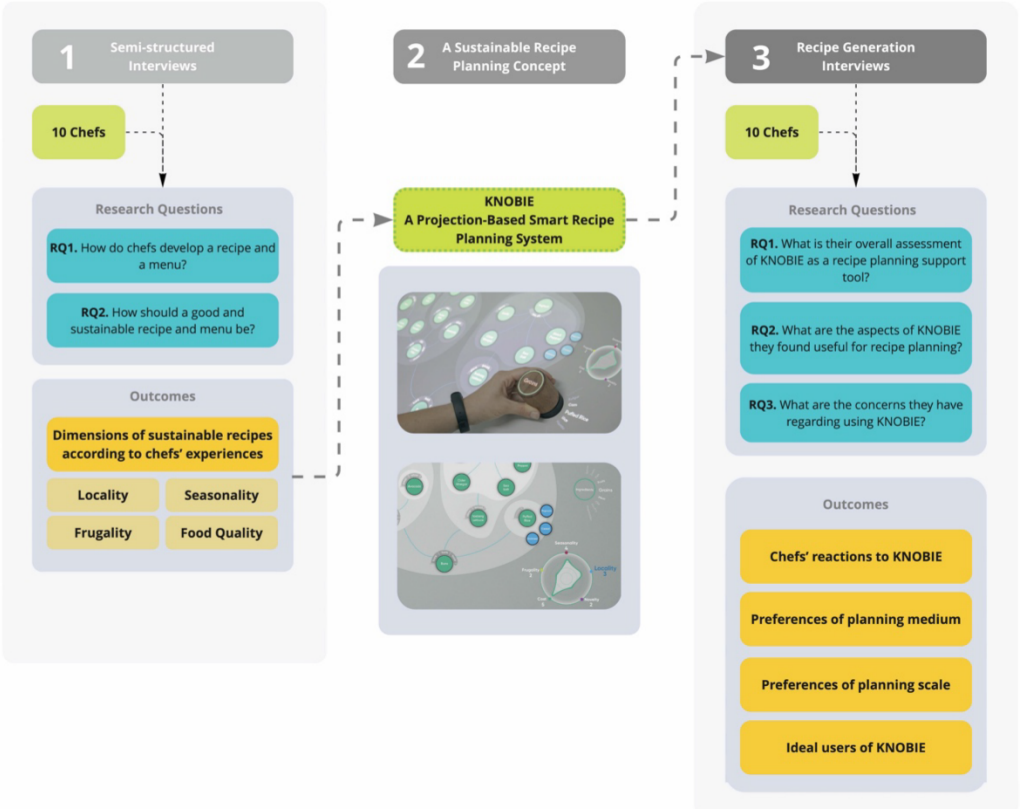


**Figure 1: Study Stages**

food waste through simulation and modeling software, and inventory management applications quantifying consumer food waste [47]. On the other that, studies focused on exploring ICTs' role in designing digital menus and exploring customers' reactions to digital menus [19, 48]. Furthermore, while some technology adoption studies in the food service industry have focused on consumer and manager adoption of ICTs [16, 63], there is a lack of research exploring how chefs perceive technologies that support sustainable menu and recipe planning practices. In other words, it is currently unknown how ICT-based solutions could support sustainable menu and recipe planning practices in restaurants.

This paper addresses these research gaps by presenting a study of 20 chefs' recipe planning practices and reactions to a novel sustainable recipe planning concept called KNOBIE. It offers three contributions to the literature. First, it reveals the characteristics of sustainable menu and recipes in restaurants based on chefs' insights, i.e., locality, seasonality, frugality, and food quality. Second, it presents a new interactive tool for supporting sustainable menu and recipe planning practices. Third, based on an assessment of this concept through online recipe generation sessions, it provides implications for incorporating ICT-based solutions into recipe and menu planning practices to promote sustainable foodservices.

## 2 BACKGROUND

### 2.1 Sustainable Food Services

Sustainable food service operations aim to be profitable, beneficial to society, and environmentally neutral [42]. Researchers, industry associations, and third-sector organizations have established standards for sustainable food service operations. For instance, Green Restaurant Association (2022) indicates that sustainable food services require energy and waste reduction, water efficiency, sustainable furnishings, building materials, and food for certification. However, sustainability in the food service industry is often discussed regarding operational efficiencies ([30]).

All food-related operations in restaurants affect the sustainability of food services. For instance, locally or regionally sourced food reduces transportation routes and CO2 emissions [29]. Applying resourceful cooking techniques such as proper trimming and reusing vegetable cut-offs are among the ways to achieve sustainable kitchen operations [17]. The presentation of the food (e.g., attractive and tasty) [66] and food-related behaviors of consumers (e.g., leaving leftovers) [59] also contribute to the sustainability of food services.

Sustainable food service operations involve various stakeholders with different economic, environmental, and social goals (i.e., managers, chefs, suppliers, consumers, and service personal). Therefore, to achieve sustainability, all food-related operations, from procurement to consumption, must consider the needs of these stakeholders.

This study focuses on menu and recipe planning practices in food preparation, as they influence other operations and are critical for achieving sustainability, and chefs as stakeholders since they are the key decision-makers in kitchen operations.

## 2.2 Sustainable menu and recipe planning

Menu composition and planning are crucial in sustainable food service operations, influencing purchasing, serving, and consumption decisions. Chefs play a significant role in menu and recipe planning due to their culinary expertise [31]. Planning a sustainable menu and recipe involves concurrently considering multiple economic, operational, and marketing factors, including cost, profitability, gastronomy, infrastructure, marketing, and quality [27, 56]. Chefs must prioritize ingredient locality and seasonality, cost management, and feasibility of the menu for the kitchen staff when creating sustainable menus [12, 30, 34]. Previous research on chefs' perspectives on menu planning has explored various aspects, the process [56], post-COVID changes [6], supplier relationships [41], and menu profitability [33], but lacks methods for assessing menu and recipe sustainability. However, sustainability assessment has been largely unaddressed in these studies.

New technologies could considerably improve menu and recipe planning practices towards more sustainable practices [15]. For instance, food services prefer locally produced food due to its convenience, affordability, and consistency of product supply [52], as well as sustainability benefits such as healthiness, taste, nutritional quality, and food miles [55]. However, ensuring the quality of the food when using local food and developing seasonal recipes is crucial [43]. An ICT-based menu planning tool could help chefs track food from its production in the field to procurement through smart tags, thus helping better judge the quality and locality of the ingredients. Despite the ICTs' potential contributions to sustainable food operations and the existence of few commercial tools (e.g., Event Food Carbon Calculator [38]), the literature lacks studies giving attention to how ICT-based solutions can support sustainable menu and recipe planning in restaurants, and how chefs as the key decision makers in the menu and recipe planning react to such solutions.

# 3 METHOD

To positively impact menu and recipe planning practices, an ICT-based solution should gain acceptance from prospective users [62], and, thus, be designed according to user needs. User-centered design (UCD) has been the standard methodology to ensure this requirement by involving users in the various stages of the design process, such as problem framing, ideation, and testing [1, 24]. Against this backdrop, the KNOBIE concept was designed using a three-phase UCD approach. The phases were interviews with chefs, the initial design of KNOBIE, and recipe generation sessions (Figure 1, previous page).

During the first and third phases, the data collection methodology was based on qualitative inquiry [10]. These phases involved 20 chefs recruited through social media and a snowballing strategy [67]. Sixteen chefs also work as managers of their restaurants, i.e., chef-owned restaurants. Three of the chefs were culinary instructors. The sample included chefs working in various types of restaurants ranging from fine dining to fast casual and chefs with various experience levels. (See Table 1 in the next page for participant characteristics).

## 3.1 Phase 1: Interviews with chefs

In the first phase, semi-structured interviews were conducted with ten chefs (P1-P10) to investigate their recipe preparation practices and attitudes toward integrating sustainability into these practices. The sample size was determined by data saturation, achieved when chefs' contributions become repetitive, and no further information was revealed [53]. Interviews began with general questions about chefs' professional backgrounds and gradually delved into their personal approach to planning, ingredient selection, and kitchen sustainability. The interviews were structured around two broad questions: 1) How do chefs develop a recipe, and 2) How should a good and sustainable recipe be?

## 3.2 Phase 2: Designing KNOBIE

In the second phase, a recipe planning concept, the KNOBIE, was designed in response to chefs' demand for an interactive platform to help them develop sustainable recipes while considering the four aspects of the locality, seasonality, frugality, and food quality. Its design was motivated by the comprehensive interviews with chefs, which revealed their needs and constraints in recipe planning, particularly regarding sustainability. As a result, the development of KNOBIE was grounded not only by the need for sustainability in the culinary world but also by the practicality of its use in a real-life kitchen setting.

The KNOBIE consists of an interactive knob and a projected display. Based on these findings (see Results-Dimensions of Sustainable Recipes section below), it enables chefs in two main activities. First, chefs can create recipes by selecting and adding ingredients using the knob. They can record and retrieve their previous recipes, custom ingredients, and combinations for personalized use. Second, during recipe planning, KNOBIE simultaneously assesses and gives real-time feedback about the sustainability of a recipe according to locality, seasonality, and frugality, and the quality of a recipe according to cost and novelty. For example, while a chef picks some ingredients for a recipe, the spider diagram on the bottom right of the projected display shows the recipe's performance according to these criteria. This feedback changes as the chef replaces or adds new ingredients (see Figure 2).

Seasonality, locality, and cost are assessed by compiling data from the ingredients in the recipe since each ingredient is valued for each dimension. Assessment for novelty is done by examining the combinations of ingredients and cooking techniques. Frugality is assessed by comparing the used and unused parts of an ingredient. Chefs can also prioritize a dimension over others by directly selecting it, such as creating a seasonal recipe vs. a frugal recipe. Upon recipe assessment, KNOBIE makes ingredient suggestions to improve a recipe according to the selected dimensions (see Figure 2).

## 3.3 Recipe generation sessions

In the third phase, online recipe generation sessions were conducted with ten chefs (P11-P20) to gather their reactions to using

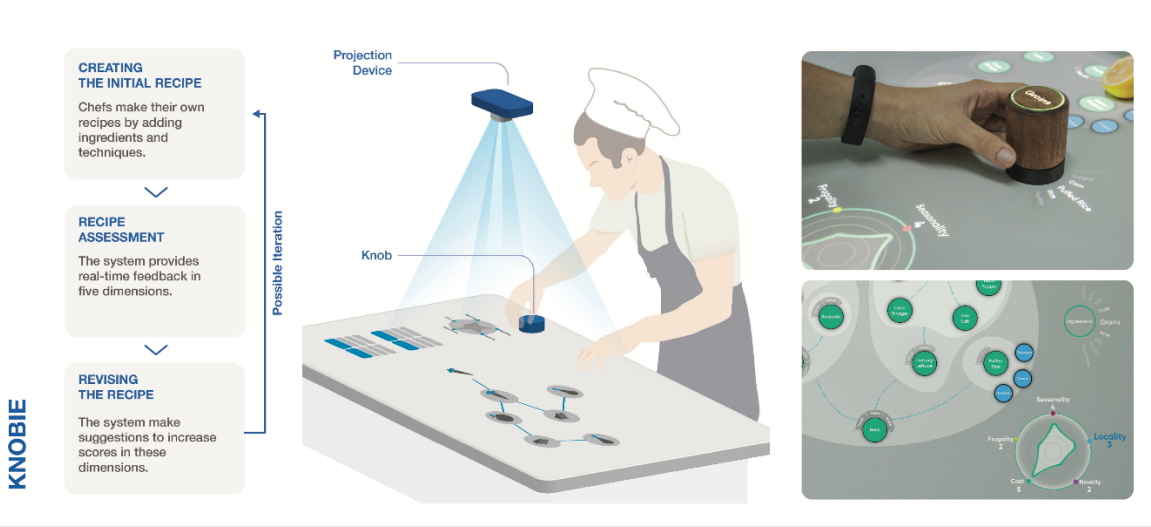


**Figure 2: KNOBIE recipe planning system 1) User Flow, 2) Conceptual Illustration, 3) Photos of the system prototype**

the concept. Miro and Zoom were used to moderate and record the sessions. This setup was prepared because installing KNOBIE in chefs' kitchens and conducting face-to-face interviews were not possible due to COVID-19 restrictions when the study was conducted. To mimic KNOBIE's usage in an online setting, a Miro template with graphic cards for ingredients, cooking methods, tools, etc., was designed. First, the KNOBIE concept and the recipe generation templates were introduced to chefs. Second, chefs developed recipes using the templates for about 25 minutes. During this phase, the researchers guided the chefs when they needed help on Miro and did not interfere with the recipe planning process. Third, chefs were asked to evaluate KNOBIE and share their opinions about the recipe generation process. The part concerned three main questions: 1) What is chefs' overall assessment of KNOBIE as a recipe planning support tool? 2) What are the aspects of KNOBIE they found helpful for recipe planning? 3) What are the concerns they have regarding using KNOBIE?

## 3.4 Data analysis

Data from semi-structured interviews (Phase 1) and recipe generation sessions (Phase 3) were audio-recorded and analyzed through qualitative coding [39] by combining deductive and inductive approaches. The recordings were transcribed into text. The authors labeled the data using questions as deductive categories, such as chefs' recipe preparation practices, characteristics of a sustainable recipe, and reactions to KNOBIE. Themes were created through an inductive approach, including characteristics of a sustainable recipe such as locality, seasonality, and frugality or analog vs. digital recipe preparation as chefs' preferences of the medium for recipe planning.

# 4 RESULTS

The results are presented in two sections. While the first section explains chefs' perceptions of a sustainable and good recipe, the second section presents their reactions to KNOBIE.

## 4.1 Dimensions of sustainable recipes

According to participant chefs, a good recipe should be novel (using new cooking techniques or new ingredients), cost-effective (consuming fewer resources like money and time to deliver good value), and sustainable (being respectful to the environment). During the interviews, chefs mentioned that they would use locality, seasonality, and frugality to assess the sustainability of a recipe. This perception of a sustainable recipe aligns with the academic literature, even though any criterion was not mentioned during the interviews to avoid priming the participants. On the other hand, chefs noted that addressing these criteria has benefits beyond reducing a restaurant's environmental impact. Hence, the study provided results confirming and advancing previous work regarding the characteristics of sustainable recipes and menus.

*4.1.1 Locality.* Food procurement is restaurants' most significant source of environmental impact [4]. The decision on food transport influences its impact on GHG emissions [18]. Chefs' practices align with this information, stating that using locally produced ingredients from local suppliers is a precondition for sustainable recipes. However, according to them, the locality has benefits beyond reducing environmental impacts. For instance, eight chefs thought that while reducing food mileage is good for the environment (e.g., supplying products up to 50 km), it also supports the local producers and, thus, the local economy.

Despite all the benefits of using local ingredients in recipes, ensuring the locality of an ingredient is a complicated task. Vargas et al. [61] point out that it would be wrong to assume that local food always has less environmental impact than globally acquired food. Advancing on this previous work, the interviews revealed

**Table 1: Participant characteristics for the semi-structured interviews**

| | Gender | Occupation | Experience in years (XP) | |
|---|---|---|---|---|
| P1 | F | Chef & Manager | 9 | Street Truck |
| P2 | F | Chef & Manager | 18 | Contemporary Casual |
| P3 | F | Chef & Manager | 18 | Fine-Ethnic |
| P4 | F | Chef | 6 | Fine-Ethnic |
| P5 | M | Chef & Manager | 9 | Fast Casual |
| P6 | M | Chef & Manager | 12 | Fast Casual |
| P7 | M | Chef | 19 | Fine dining |
| P8 | F | Chef & Instructor | 12 | Instructor in Culinary Arts |
| P9 | F | Chef & Instructor | 15 | Instructor in Culinary Arts |
| P10 | M | Chef & Instructor | 13 | Instructor in Culinary Arts |
| P11 | F | Chef & Manager | 7 | Fast Casual |
| P12 | M | Chef & Manager | 8 | Fast Casual |
| P13 | M | Chef & Manager | 5 | Fast Casual |
| P14 | M | Chef & Manager | 6 | Fast Casual |
| P15 | M | Chef & Manager | 7 | Fast Casual |
| P16 | F | Chef & Manager | 7 | Yacht Private Chef |
| P17 | F | Chef & Manager | 7 | Fine-Ethnic |
| P18 | F | Chef & Manager | 4 | Fine-Ethnic |
| P19 | F | Chef & Manager | 9 | Street Truck |
| P20 | M | Chef & Manager | 8 | Fine-Dining |

that knowing whether an ingredient is local is not always possible since a supplier can sell exported produce under the name of local produce, or local farmers can use hybrid seeds instead of local ones, as indicated by three chefs. Four chefs added that a lack of knowledge about the food's production chain creates uncertainty about the locality. These chefs reported that they prefer to work with trustworthy suppliers to know more about the food's journey into their kitchen, thus, ensuring that they use authentic local ingredients. This finding implies that the trust between food service stakeholders (in this case, between chefs and food suppliers) is critical for buying local food.

*4.1.2 Seasonality.* Seasonality is closely related to locality from an environmental impact perspective. Gössling et al. [18] indicate that importing out-of-season products requires significant energy for transportation and storage, compared to using local and seasonal products. In line with this, during the interviews, all the chefs indicated that they tried to use local and seasonal ingredients to minimize their restaurants' environmental impact. However, the interviews also revealed new insights. For instance, three chefs emphasized that understanding the natural growing season of the food was a required chef skill. Accordingly, chefs found that using seasonal ingredients was not only beneficial for the environment but also nurturing their creativity. Four chefs have a common practice of forbidding their team from using off-season ingredients and encouraging them to create new recipes using seasonal ones. This finding illustrates the benefit of creating sustainable recipes and menus beyond reducing environmental impact.

*4.1.3 Frugality.* Frugality is being careful when consuming resources (i.e., food) and minimizing waste. Frugality has a moral dimension [14]; creating food waste is considered immoral [46, 47]. In line with this notion, all the chefs were very sensitive about the frugal use of resources, waste reduction, and respect for food as a material. To them, frugality is required not just for preserving the environment but also for reducing costs to maintain the business.

The interviews uncovered a significant finding about frugality. Chefs consider frugality not for a specific recipe or dish but for the menus. Chefs used two approaches to address frugality. The first is using all the edible parts of the food, known as "root-to-stem." The second is offering residues as side dishes; for example, a surplus of anchovies can be served as a paste along with the main dish, or new meals can be created from leftover ingredients. However, according to chefs, these approaches have limitations since the menu should balance ingredients and taste. For instance, one chef stated they did not use zucchini fritters and fried zucchini shells in the same dish because customers might expect different flavors and textures throughout their dining experience.

Moreover, chefs reported that although they were careful about the frugal use of resources, customers might not always want to eat food prepared based on a frugal recipe, i.e., a recipe prepared by using surplus food or the entirety of a food, supporting previous work [2]. In this respect, chefs emphasized the importance of creating balanced recipes and menus that help minimize food waste without worsening customers' eating experiences. These findings illustrate the importance of considering customers' preferences when designing sustainable recipes.

*4.1.4 Food quality.* Chefs perceived seasonality, locality, and frugality as critical for developing sustainable recipes. However, the interviews showed that the quality of ingredients in a recipe heavily influences their decisions about using local and seasonal products

and using them in a frugal way. For example, chefs indicated that they would only use a locally produced ingredient if it were of high quality. They thought local producers' limited production capacity could decrease food quality to satisfy large orders. Hence, they considered the consistency and sustainability of local product supplies when adding ingredients to their recipes and menus.

As for the seasonality, on the one hand, all the chefs stated that the off-season products were tasteless, colorless, and odorless, which could not meet their expectations in terms of quality. On the other hand, a chef argued that menus should be flexible in using replacement ingredients because it was hard to get high-quality seasonal ingredients. According to her, this flexibility ensures the provision of high-quality local produce and satisfies the customers' desire to consume local and quality food. As opposed to this, three chefs stated that the menu should change every 1-1.5 months to adapt to seasonal changes. These chefs added that they used a seasonal ingredient not just because it was seasonal but because it was high quality. One chef explained that he even grew his produce to use seasonal and high-quality food. Finally, regarding frugality, a chef said that food quality was the most important thing. He would rather throw an ingredient away if the quality were low than serve it.

*4.1.5 Chefs' general reactions to using KNOBIE for recipe planning.* When KNOBIE was introduced to chefs during the recipe generation interviews, their overall reaction was very positive. They all find assessing a recipe's novelty, cost, and sustainability essential. Nine out of ten chefs stated that the sustainability dimensions are convenient. Four chefs liked the suggestion mode.

Four chefs considered KNOBIE as a tool to mitigate food waste by encouraging them to create frugal recipes. They argued that it could be more beneficial for large-scale restaurants (e.g., hotel kitchens) as these places produce many dishes and are thus prone to creating more waste. Other chefs said that it could also be helpful for consultant chefs, who work in the research and development departments of hospitality companies such as chain restaurants, to experiment with new recipes or for coordinator chefs, who plan recipes and menus for multiple restaurants, to give instructions about a recipe and its components to other cooks and chefs.

Although nine chefs found KNOBIE useful for their work, one chef stated that its assessment has yet to have added value for an experienced chef who knows a good season for a specific ingredient. The observations during the recipe generation sessions confirm this statement. When chefs were asked to evaluate their recipes regarding material selection, all stated that they used seasonal ingredients. For instance, one chef said, "*Because now is the best time for asparagus. During this period, it is both very cheap and delicious.*" (P15).

Furthermore, three chefs said that knowing the locality and seasonality of an ingredient would be helpful for junior chefs as it could help them enhance their knowledge about materials and cooking techniques. On the other hand, one chef emphasized that although experienced chefs can judge the seasonality and locality of an ingredient, they cannot judge the cost, as ingredient prices constantly shift. This chef stated that KNOBIE could have additional value if it shows actual ingredient costs precisely.

## 4.2 Chefs' preferences of the medium for creating recipes

KNOBIE allows chefs to create a recipe by dragging and dropping ingredients and cooking methods and connecting them through arrows, i.e., by creating a visual recipe diagram. During the recipe generation sessions, the chefs utilized KNOBIE in different ways. Four chefs created a flow diagram for the recipe and detailed all the steps in a textbox. One chef also wrote the details between the steps in the flow diagram. Six chefs moved the cards (ingredients, tools, and cooking techniques) to the recipe area without using a flow diagram. These chefs later rewrote the entire recipe in a text box. In other words, more than half of the chefs preferred to write their recipes than comply with KNOBIE's interaction scenario (Figure 1).

While chefs in the first interviews stated they were good with technology, all ten chefs who participated in the recipe generation sessions said they would need help to create recipes using a digital tool. Though this difficulty might be partly due to their unfamiliarity with the online collaboration tool Miro, four chefs explicitly stated that they preferred to use paper and pencil in their recipe planning processes. They added that recipe planning did not happen at a specific time and said that when they found inspiration in a book, an ingredient, or a fragrance, they immediately took notes in their notebook. In this respect, some chefs perceived writing a recipe in a notebook as more advantageous than KNOBIE due to its convenience and directness. However, this does not mean chefs do not welcome ICTs into their practices. For instance, one chef said the following:

> "I take notes on paper whenever something inspires me. After trying it a couple of times, I create the recipe and store it on my computer. I create a template in Excel. I write details like product weight, technique, how it is made, when it is made, and where it can be used. It is much easier for me to reach them in the digital environment. When I search for a specific material, for example, grape leaves, they all appear before me." (P13)

## 4.3 Chefs' insights into the suitability of using KNOBIE in recipe planning

All the chefs stated that recipe planning was an ongoing process and that creating and perfecting a recipe took time. They added that this process involves different activities (thinking about the materials, notetaking, experimenting, conducting test sessions, etc.). In this respect, three chefs specified that KNOBIE might be limited for recipe planning, but adaptation to menu planning could increase its usefulness. For instance, these chefs expected to obtain suggestions from KNOBIE at the menu level, e.g., whether different dishes are compatible in terms of taste and texture, rather than the recipe level, e.g., whether they should replace an ingredient in a recipe to increase seasonality as this would mean changing the original recipe. They explained that applying the replacement suggestions was more manageable once they had a good recipe. One chef illustrated this with the following:

> "Let us say that I am making a menu with five courses. It is like playing a puzzle. For example, I can look at

> whether I have legumes on the menu. If yes, 'do the menu include items that can go well with it?' When thinking about food, we do not start with the recipe but with the categories of materials in a menu. If the tool makes suggestions at the menu level, it would be useful." (P16)

# 5 DISCUSSION

Sustainable menu planning requires the consideration of various economic, operational, and marketing aspects concurrently supporting chefs' sustainable recipe planning practices [20, 38]. This paper focuses on designing and assessing a novel interactive artifact to support chefs' sustainable recipe planning practices. The results emphasized the significance of locality, seasonality, and frugality in evaluating the sustainability of the recipes, supporting previous work [12, 27, 28, 35].

A closer look into the study findings showed that the study revealed novel insights. First, it was found that addressing these sustainability dimensions has beyond environmental benefits. While using local and seasonal ingredients and frugally using them reduce costs (providing economic benefits), commitment to using seasonal recipes nurtures chefs' creativity and helps improve their cooking skills (providing individual and social benefits). This finding is critical, considering that most of the literature on sustainable restaurant management frames sustainability mainly from an environmental point of view [22]. Second, the results indicated that food quality is an overarching criterion influencing chefs' decisions about using local or seasonal ingredients and frugally using these ingredients. Third, it was found that creating local, seasonal, and frugal recipes and menus is not possible for various reasons despite chefs' and managers' willingness. For instance, the results indicated that a lack of knowledge about the food production chain and trust among stakeholders serve as barriers to using local ingredients. Furthermore, although demand for local and seasonal ingredients seems to exist, consumers' reluctance to eat such meals can hinder the impact of creating frugal recipes.

This paper also contributes to the literature by introducing KNOBIE, an ICT tool to support chefs' sustainable recipe planning practices. Designing such a tool allowed the researchers to examine chefs' reactions toward KNONBIE and similar tools. Based on chefs' positive reactions to KNOBIE, the paper revealed that such technologies could alleviate the challenges and complexity of the sustainable menu and recipe planning practices, as described above. Aside from positive reactions, the paper helped determine chefs' concerns about using such a technology during recipe and menu planning, which can shed light on the design of future technologies. Accordingly, both chefs' positive comments and concerns were synthesized into six implications for designing new technologies to support sustainable recipe and menu planning practices and incorporating them into restaurant kitchen operations. The remainder of this section presents these implications.

## 5.1 Use tangible artifacts from chefs working environments as input devices

Chefs work in a hands-on fashion. They use notebooks and sketches to visually record recipes, ideas, inspirations, and notes from trial sessions for future reference. While notebooks create a medium for ongoing exploration, their materiality [3] also helps them connect the recipe preparation process to their tactile sensations. Thus, future ICTs that support sustainable menu and recipe planning practices should utilize tangible artifacts as input devices. This consideration was reflected in KNOBIE by using a wooden knob to provide a hands-on working experience. Nonetheless, the recipe generation interviews showed that some chefs still prefer analog food preparation practices (e.g., writing in a notebook) over digital practices (e.g., using an interactive recipe planning system). In this respect, tangible user interfaces [57], which allow users to control digital information via daily artifacts derived from their working environment, might be a promising alternative. For example, in the next version of KNOBIE, chefs' recipe analog notebooks could be augmented with computer technology; a mobile app can turn notebook recipes into digital recipes via scanning.

## 5.2 Provide real-time and comparative data on the recipes and menus

The study revealed that locality, seasonality, and frugality should be considered holistically when assessing the sustainability of a recipe because they are interrelated. For instance, while using off-season products has a higher environmental impact due to importation and storage [18], it increases the cost of kitchen operations. Furthermore, these dimensions' effect depends on the time of the year and the restaurant's location. A seasonal recipe loses its sustainability value when cooked in the off-season. Hence, it is crucial for future ICTs to provide real-time and comparative data for assessing the sustainability of recipes and menus. KNOBIE concept addresses this requirement by assessing the recipe in real-time and visualizing the relationship between different dimensions as chefs work on their recipes, e.g., how adding a seasonal ingredient changes the recipe's locality and cost.

## 5.3 Combine different technologies to increase their impact on sustainable food operations

Food operations include many tasks influencing each other, from procurement and storage to preparation and consumption. Standalone technological innovations like KNOBIE can only individually address some sustainability concerns in food services. Hence, combining multiple technologies would be more effective. For example, KNOBIE aims to reduce food waste by encouraging chefs to use ingredients frugally. A smart bin that tracks and quantifies the waste produced in a kitchen (e.g., [8]) could be combined with KNOBIE to increase its effectiveness in reducing waste. Alternatively, as mentioned by the chefs, it can be combined with a system that connects local producers with chefs and restaurant managers to help chefs purchase local ingredients and meet their storage capacity and consumer demand.

## 5.4 Consider the characteristics of different food service domains

Chefs valued KNOBIE for its potential to be used in places that serve large amounts of food and require better and more systematic

inventory management. They indicated that a recipe and menu planning system would significantly reduce food waste due to spoilage if this system were connected to the inventory database of a hotel restaurant. On the other hand, the KNOBIE concept might not be ideal for small restaurants with few personnel and customers, where they believe the waste would be low. Hence, it is essential to tailor the new food service innovations to the characteristics of the service case [37]. In the case of KNOBIE, if adapted to a large-scale hotel restaurant, it could gather data on ingredients in stock and change or promote certain items to prevent spoilage and waste. This would guide chefs towards preparing recipes and menus that use abundant items in stock to prevent waste (e.g., by providing food suggestions that complement each other).

### 5.5 Gather insights from multiple stakeholders when developing new innovations

Technological innovations can contribute to sustainable kitchen operations by influencing the behaviors of food service stakeholders. For example, KNOBIE can encourage a chef to prepare a special dish made with vegetable skins, which could help reduce food waste during food preparation. However, this positive impact can be hindered if the restaurant management is unwilling to include this dish on the menu [50] or if the consumers are reluctant to choose this dish from the menu due to low environmental concerns [2, 40]. This issue was also prominent in the interviews, as chefs considered customers' preferences when using excess food to address the frugality dimension. In restaurants, multiple stakeholders, including managers, chefs, cooks, and service personnel, are actively involved in kitchen operations, ranging from purchasing, storing, preparing, and serving. The behaviors and attitudes of chefs and other stakeholders influence the sustainability of these kitchen operations [11]. Hence, innovations that address sustainable restaurant practices should not solely depend on a single stakeholder [13] and consider the opinions of all the relevant stakeholders.

### 5.6 Facilitating KNOBIE's adoption by considering chefs' recipe development routines

The researchers' purpose of designing KNOBIE was not to design a finalized commercial product which can be immediately utilized by chefs. Rather, it was to explore how chefs will react to an ICT based concept aimed at supporting their recipe planning practices by integrating sustainability into these practices. This open-ended nature of the study allowed identification of some issues that can prevent the adoption of such a technology by the chefs. For instance, using an interactive device to create a recipe might be perceived as cumbersome, particularly by experience chefs who already have a fair number of recipes developed through time. Thus, KNOBIE's adoption can be faster when it is used as an educational tool in culinary schools by junior chefs. Furthermore, as the results showed, recipe development is a process which can happen any time. Being bound to a physical location and one single artefact to create recipes might limit KNOBIE's usefulness for chef, in turn, hindering its adoption. Thus, connecting KNOBIE with both digital (e.g., smart phones) and physical artefacts (e.g., recipe notebooks) chefs used in their recipe development routines is key to KNOBIE's broader adoption by them.

## 6 CONCLUSION

Information and communication technologies can promote sustainable practices in the food service industry. However, when developing innovations with this goal, it is vital to understand the existing practices of various stakeholders in the food service sector, along with their attitudes towards these innovations. This paper is the first attempt to examine chefs' recipe planning practices from a sustainability perspective and design a concept, i.e., KNOBIE, to support these practices. The insights gathered in this paper not only showcase the potential of KNOBIE to be utilized in restaurants striving to have sustainable practices but also provide essential lessons for developers of new technologies to support sustainable menu and recipe planning practices. These lessons were discussed as implications in the paper to invite researchers and practitioners to contribute to the vision of sustainable food services. This research, like all others, had limitations. It may not be possible to generalize the results to all ICTs-based innovations as they are based on the experiences of a specific sample. Thus, more studies are needed to create validated design guidelines for developing new solutions to reduce the environmental impact of food services.

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