UNIVERSITY OF CRETE

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AmIChef: Supporting the cooking process in the Intelligent Kitchen

by

Konstantina Manoli

MSc Dissertation Presented in Partial Fulfillment

of the Requirements for the Degree of

Masters' of Science degree in Computer Science

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To my family

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Abstract

Meal preparation is undoubtedly an important daily activity for a vast majority of individuals, not only because food is essential for our survival, since it offers the necessary nutrients to our body, but also due to the fact that cooking is a pleasant activity offering multiple benefits (e.g. leisure, relaxation, creativity, training). Nevertheless, cooking is not straightforward; on the contrary, it constitutes an extremely complicated process, which entails intuition, self-organization, coordination, monitoring and execution of multiple tasks simultaneously, while it depends on the cook's ability to manage (even with great precision) the necessary time constraints. Given the iterative nature of cooking, along with its complexity and importance, various attempts have been made to enhance the cooking process, by devising technological solutions. Especially during the last few years, an abundance of smart devices, objects and services have been gradually integrated in a non-intrusive and often transparent way into domestic environments, offering various opportunities to the inhabitants.

The AmIChef platform is a context-sensitive cooking system that supports the resident of an Intelligent Home in preparing a meal in the kitchen, by providing interactive, multimodal, intuitive, and personalized support, while simplifying the overall process by reducing the user's mental load. The user interacts with the technological equipment of the Smart Kitchen, which mainly consists of large interactive displays, in order to: a) browse recipes, b) manage kitchen inventory, c) plan meals, and d) navigate across previously prepared meals.

AmIChef enables users to initially browse through automatically curated lists of recipes (based on their personal profile), then customize them according to their preferences, and finally execute them while receiving real-time feedback with respect to the steps, ingredients, utensils, time, and actions to be taken. In particular, AmIChef presents for each step the ingredients and the cooking utensils users have to collect from the surrounding environment along with the actions they need to perform. The AmIChef's objective is to ensure that a user can prepare a meal as easily, quickly, safely and efficiently as possible.

This thesis: (a) presents an approach towards supporting the meal preparation process from the perspective of intelligent environments; (b) reports on existing systems highlighting their shortcomings and the potential for improvements; (c) describes the adopted design methodology and the functionality of AmIChef; and (d) documents the results of a series of expert-based evaluation in the context of an Intelligent Home.

Περίληψη

Η προετοιμασία γευμάτων αναμφισβήτητα αποτελεί μια σημαντική δραστηριότητα στην καθημερινή ζωή πολλών ανθρώπων. Όχι μόνο γιατί, από βιολογικής σκοπιάς, η τροφή παίζει θεμελιώδη ρόλο στη ζωή μας καθώς μας προσφέρει όλα τα απαραίτητα θρεπτικά συστατικά για να επιβιώσουμε, αλλά και γιατί η μαγειρική αποτελεί μια ευχάριστη δραστηριότητα με πολλαπλά οφέλη (π.χ. αναψυχή, χαλάρωση, δημιουργικότητα, εκπαίδευση). Ωστόσο, η διαδικασία του μαγειρέματος αποτελεί μια περίπλοκη δραστηριότητα που απαιτεί διαίσθηση, αυτό-οργάνωση, συντονισμό, παρακολούθηση και εκτέλεση πολλαπλών εργασιών παράλληλα, ενώ στηρίζεται στις οργανωτικές δεξιότητες του μάγειρα για την διαχείριση - ακόμα και με εξαιρετική ακρίβεια - των κρίσιμων χρονικών περιθωρίων που απαιτούνται. Δεδομένης της επαναληπτικότητας, της πολυπλοκότητας αλλά και της σημαντικότητας της διαδικασίας του μαγειρέματος, η τεχνολογική υποστήριξή της έχει αποτελέσει ένα σημαντικό ερευνητικό θέμα, ειδικά τα τελευταία χρόνια όπου και πλήθος έξυπνων συσκευών, αντικειμένων και υπηρεσιών ενσωματώνονται με μη-επεμβατικό και συχνά μη-ορατό τρόπο στα οικιακά περιβάλλοντα.

Η πλατφόρμα 'AmIChef' είναι ένα σύστημα μαγειρικής με επίγνωση του πλαισίου χρήσης (context-sensitive), που υποστηρίζει τον κάτοικο ενός έξυπνου σπιτιού και του παρέχει διαδραστική, πολυτροπική, πολυαισθητική, και εξατομικευμένη υποστήριξη, ενώ βρίσκεται στο χώρο της κουζίνας και προετοιμάζει ένα γεύμα, στοχεύοντας στην απλοποίηση της συνολικής διαδικασίας μέσω της μείωσης του νοητικού φόρτου. Ο χρήστης μέσω της αλληλεπίδρασης με τον τεχνολογικό εξοπλισμό της Έξυπνης Κουζίνας, ο οποίος αποτελείται κυρίως από μεγάλου μεγέθους οθόνες αφής, μπορεί: α) να περιηγηθεί σε μαγειρικές συνταγές, β) να διαχειριστεί τις προμήθειες της κουζίνας, γ) να προγραμματίσει γεύματα, και δ) να πλοηγηθεί στο ιστορικό των γευμάτων που είχε προετοιμάσει στο παρελθόν.

Βασική λειτουργικότητα του συστήματος είναι η περιήγηση του χρήστη σε εξατομικευμένες προτάσεις για συνταγές μαγειρέματος έχοντας τη δυνατότητα παραμετροποίησης αυτών ανάλογα με τις προτιμήσεις του, όπως και η δυνατότητα εκτέλεσης των συνταγών αυτών με πραγματικού χρόνου ανάδραση σχετικά με τα

βήματα, τα υλικά, τα μαγειρικά σκεύη, τον χρόνο και τις ενέργειες που χρειάζονται, έτσι ώστε να ολοκληρώσει τη συνταγή. Ο χρήστης έχει τη δυνατότητα προβολής των βημάτων της συνταγής σε συνδυασμό με τα υλικά και τα μαγειρικά σκεύη που χρειάζεται να συλλέξει από τον περιβάλλοντα χώρο ανά βήμα, όπως και τις ενέργειες στις οποίες χρειάζεται να προβεί κατά τη διαδικασία εκτέλεσης των μαγειρικών βημάτων. Στόχος είναι η δημιουργία του μαγειρικού αποτελέσματος με όσο το δυνατόν εύκολο, γρήγορο, ασφαλές και αποτελεσματικό τρόπο.

Η εργασία αυτή παρουσιάζει: (α) μια προσέγγιση για την υποστήριξη της διαδικασίας προετοιμασίας γευμάτων υπό το πρίσμα των ευφυών περιβαλλόντων, (β) εκτενή αναφορά σε παρόμοια συστήματα αναδεικνύοντας τα υφιστάμενα κενά τους, (γ) λεπτομερή περιγραφή της διαδικασίας σχεδίασης και της λειτουργικότητας του συστήματος AmIChef, και (δ) καταγραφή των αποτελεσμάτων αξιολόγησης του συστήματος AmIChef με τη συμμετοχή ειδικών ευχρηστίας (UX experts) στο πλαίσιο ενός «Εξυπνου Σπιτιού».

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Chapter 1
Introduction

Cooking is a central activity of daily life that requires intuition, self-organization, coordination, multitasking and time-critical planning skills. Cooking takes place inside the kitchen environment, which according to L. C. Johnson [1], is the environment where work blends with desire, enjoyment, imagination, safety and other people, and where domestic technology, architects and designers create devices and space. The kitchen is either a private fixed space, separated from the other spaces of the home or an open one, while it is equipped with a variety of cooking ingredients, utensils and devices that assist the residents in their everyday tasks related to kitchen activities, such as cooking, washing the dishes and preparing daily meals. The kitchen is also a communication environment between the residents of the home, since many people use the kitchen as a place for entertainment during or while waiting for their meal to be prepared. This room has been the subject of tremendous changes over the last 100 years in Western countries, with respect to its size, location, equipment, look and social relationships that take place in a kitchen, while new and more complex cooking aids that support the cooks during their activities are constantly created.

When cooking, people often follow recipes, (either from memory, or cookbooks, or from a digital media), while it's not unusual to experiment and discover new custom variations of recipes. Traditionally, a cooking recipe is a written textual description, which sometimes may portray the required steps in an imprecise manner, or entail inconsistencies regarding the quantities of the ingredients. Additionally, when individuals follow written recipes, they may lose track of the step they should follow, misinterpret the required amount of ingredients because of complex measuring units, or even forget to add an ingredient. This happens because the written recipe and the actual steps needed in the cooking process that a person will perform in their kitchen environment are different. The user is called to transform the written recipe steps into actual executable plans that are used in complete cooking situations.

During the past years, cooking recipes are being digitalized so as to be accessible through PCs and mobile devices, including smartphones and tablets. Researchers have attempted to enrich the cooking process for the digitized recipes integrating multimedia, and embedding technologies in various kitchen artifacts. However, to this day, there is not a holistic approach that supports the users throughout the entire process of cooking, while the way cooking support systems can be tailored to the personalized needs of each cook on the basis of their cooking ability and skills remains a topic for discussion.

In the recent past, the kitchen environment has been the subject of many research projects that explore the application of technology in real-world contexts, so as to support people while performing cooking activities. With the proliferation of Ambient Intelligence Environments, and as technology turns out to be more ubiquitous in the home [2], kitchens have become one of the first rooms of the house that incorporate state-of-the-art technologies to support the residents in their daily activities. Ambient Intelligence (AmI) refers to "a vision of the Information Society where the emphasis is on greater user-friendliness, more efficient services support, user-empowerment, and support for human interactions" [2] . In an AmI environment, intelligent and intuitive interfaces are embedded in various everyday objects, and the recognition and response to the presence of people is possible in a seamless, unobtrusive and usually invisible manner. AmI environments take advantage of sensors, networks, pervasive computing, and artificial intelligence in order to be sensitive, responsive, adaptive, transparent, ubiquitous, and intelligent [3]. Additionally, upon the arrival of the Internet of Things (IoT) [4] more and more kitchen appliances are being connected to the network and the necessity for interoperability and interconnection between them grows. Thanks to AmI and IoT, inside an Intelligent Kitchen numerous items and artifacts (e.g., kitchen counter, scale) are equipped with sensors that are used to gather information about their usage, and are able to act without human intervention whenever required [3]. Additionally, such an environment possesses intelligence and is able make decisions based on its state and interactions with its residents. AmI and IoT offer access to numerous technological tools, which can be used to support people in their kitchen tasks and the cooking process, save precious time, and learn new capabilities related to the culinary art. Additionally, by interacting with various interconnected objects, tools and

displays that turn into sources of information and communication, the users can experience an enhanced cooking process.

This study introduces AmIChef, an assistive cooking system that aims to support the residents of Intelligent Homes by providing interactive, context aware, multi-modal, multisensory, user-adaptive and intuitive help while they prepare a meal. AmIChef will be integrated in the technologically enhanced kitchen of the ICS-FORTH's Intelligent Home. This Intelligent Kitchen is equipped with common kitchen appliances and devices as well as custom-made artifacts with embedded displays and sensors (e.g. smart countertop, smart backsplash). AmIChef aspires to use the ambient facilities of the Intelligent Kitchen so as to support of the cooking process, decrease the perceived complexity of unfamiliar recipes, increase residents' confidence about the success of intermediate steps, and finally reduce users' inhibitions of using technology in a kitchen for fear of damaging it. The main goal is to offer a cooking experience, providing useful feedback, tips, and motivation. The system provides sophisticated and effective guidance according to the cooking skills and preferences of each resident, so as to cater for the needs of inexperienced cooks, but also to support users with advanced cooking skills when they need it. Additionally, it offers advanced interaction techniques (e.g. voice interaction, gestures) so as to ensure that users can interact with the available interfaces even if their hands are occupied or dirty.

Since the kitchen is one of the first places that residents visit every day in order to prepare their meals and beverages, where they can potentially meet other members of their family, be socialized and entertained, it is apparent that in this room the residents should have the ability to perform various tasks not only related to the cooking process, but also to their daily schedule, socialization, or entertainment. Indicative examples of such tasks are: access and manage their home security, receive home notifications, listen to music, browse their shopping list, check the house inventory, be informed regarding the weather, etc.

To summarize, AmIChef will offer the house residents user-friendly interfaces for:

- Supporting the entertainment and socialization aspect of cooking process. Social relationships could take place inside the kitchen environment during a

planning and preparation of a meal between the residents. They are also able to access entertainment options that are provided.

- Supporting the resident prior to the cooking process during the planning actions. The resident will have the ability to browse through personalized suggestions and a variety of categorized cooking recipes. They will be able to manage their kitchen inventory, plan their meal on a daily or weekly basis and navigate across previously prepared meals.
- Supporting the resident during the preparation of a meal. After the selection and the adjustment of a recipe, the resident will be able to start the meal preparation following the required steps, which will be enriched with multimedia such us images and video. Throughout this process the system will:
    - Offers situated guidance through the kitchen environment in order to help the resident collect and prepare the required ingredients and cooking objects.
    - Adapt to the resident's preferences, meaning that the system will follow the resident in the process and not vice versa.
    - Provide real time feedback regarding the state of the recipe and kitchen environment, including an overview of the current system state, information about events that require no immediate user actions, etc.
    - Offer utilities appropriate for cooking activities (e.g. timers).

Chapter 2
Background Theory

In this chapter, before proceeding to the creation of our cooking support system, it is crucial to understand what kitchen tasks are usually performed in the kitchen and where are those tasks are located through the kitchen environment, what is the complexity of the cooking process that we are called to support through our system, what was the traditional way of cooking, how this can be transformed and digitalized, and what is the role of Ambience Intelligence (AmI) and Internet of Things (IoT) in the kitchen and cooking procedure.

2.1 Domestic kitchen design and task areas

According to L. C. Johnson [1], the kitchen environment is where work blends with desire, enjoyment, imagination, safety and socialization with other people, and where domestic technology, architects and designers create devices and space. The kitchen should be a private fixed space separated from the other spaces of the home or an open area of the living room. It has been the subject of tremendous changes over the last 100 years in Western countries with respect to its size, location, equipment, look and social relationships that take place inside the kitchen environment.

Work on improving kitchen layouts was initiated in the 1920s by Lillian Moller Gilbreth, an industrial psychologist and engineer who is called the woman who invented the kitchen [5]. The L-shaped pattern was referred by Gilbreth as "circular routing," which later came to be called the triangle of kitchen work. In the 1940s, a specific model was developed to enhance the productivity of the kitchen environment between the revealed main work centers: cooking (stove), preparation (kitchen counter/ sink) and food storage (refrigerator). The idea is to place these three centres which form a triangle shape at the most efficient distances apart to achieve the best configuration for the space available and to minimise traffic through the work zone. Those three forms The Kitchen

Work Triangle, which was created by the University of Illinois School of Architecture to emphasize cost savings by standardizing design [6]. Ideally, to achieve a compact yet workable kitchen triangle the main work centers should be positioned about 4 to 6 feet (approx. 1.2 to 2 meters) apart. The total walking distance between sink, stove and storage should not exceed 22 feet (approx. 7 meters). Ideally, there should be no major traffic flow through the triangle and the main path in front of the refrigerator, because it is annoying for people and door swings. Appliances directly opposite each other maybe cause convergent issues. For instance, the range should not be right across from the sink. Someone would be bending over to open the oven door and collide with someone who washes dishes. A full-height obstacle, such as a tall cabinet, should not come between any two points of the triangle (Figure 1).

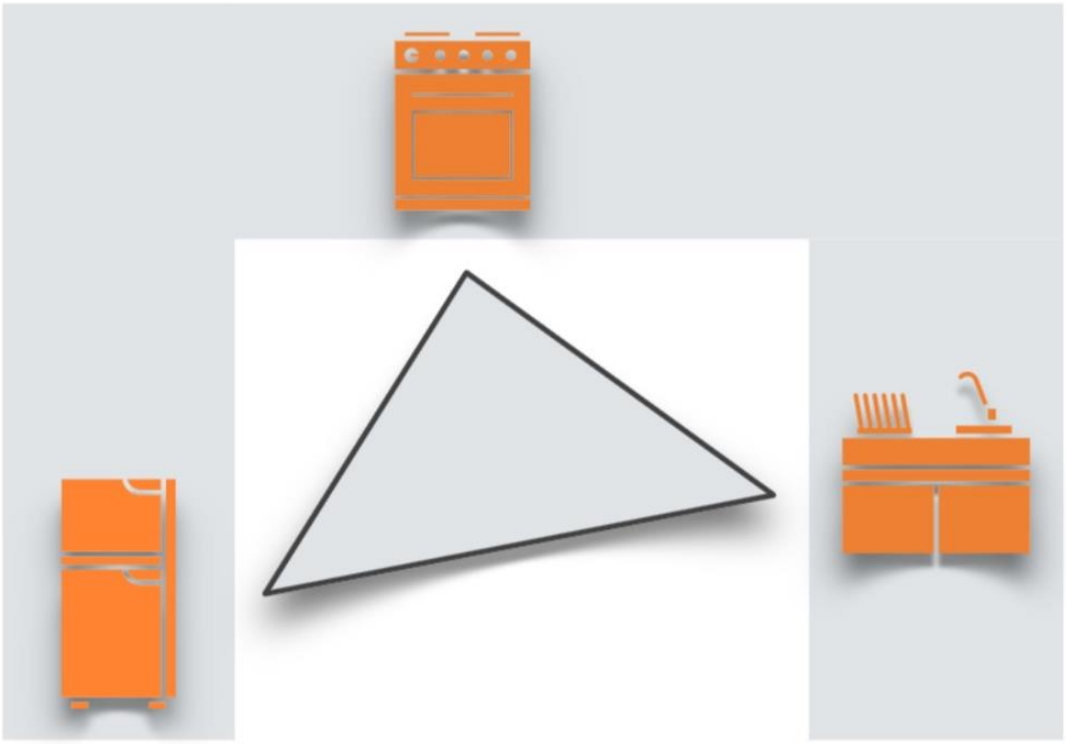


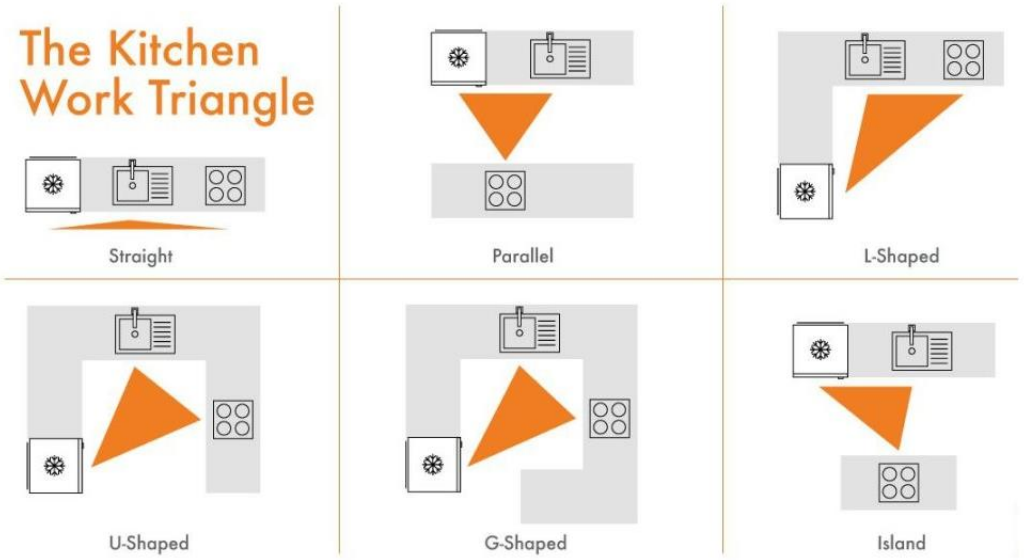
Figure 1: Kitchen Work Triangle [7]

Kitchen design led to a limited set of layouts and the standardization of bench height and widths, cupboards configuration, appliance and service location [6], [8]. From such principles there emerged six basic layouts of the well-designed kitchen [6], [9].

- The **single-line** also known as a one-way galley or a straight-line kitchen, has all of these along one wall; the work triangle degenerates to a line. This is not optimal, but often the only solution if space is restricted.
- The **parallel or galley kitchen**, has two rows of cabinets at opposite walls, one containing the stove and the sink, the other the refrigerator. This is the classical work kitchen and makes efficient use of space.
- The **U- shaped kitchen** has cabinets along three walls, typically with the sink at the base of the "U". This is a typical work kitchen too, unless the two other cabinet rows are short enough to place a table at the fourth wall.
- The **L- shaped kitchen** has cabinets occupying two adjacent walls. Again, the work triangle is preserved, and there may even be space for an additional table at a third wall, provided it does not intersect the triangle.
- The **G- shaped kitchen** has cabinets along three walls, like the U-kitchen, and also a partial fourth wall, often with a double basin sink at the corner of the G shape. The G-kitchen provides additional work and storage space, and can support two work triangles.
- The **block kitchen (or island)** is a more recent development, typically found in open kitchens. Here, the stove or both the stove and the sink are placed where an L or U kitchen would have a table, in a free-standing "island", separated from the other cabinets. In a closed room, this does not make much sense, but in an open kitchen, it makes the stove accessible from all sides such that two persons can cook together, and allows for contact with guests or the rest of the family, since the cook does not face the wall any more.

These six kitchen designs spread across the globe and continue with few variations today in most Western countries (Figure 2).

a.



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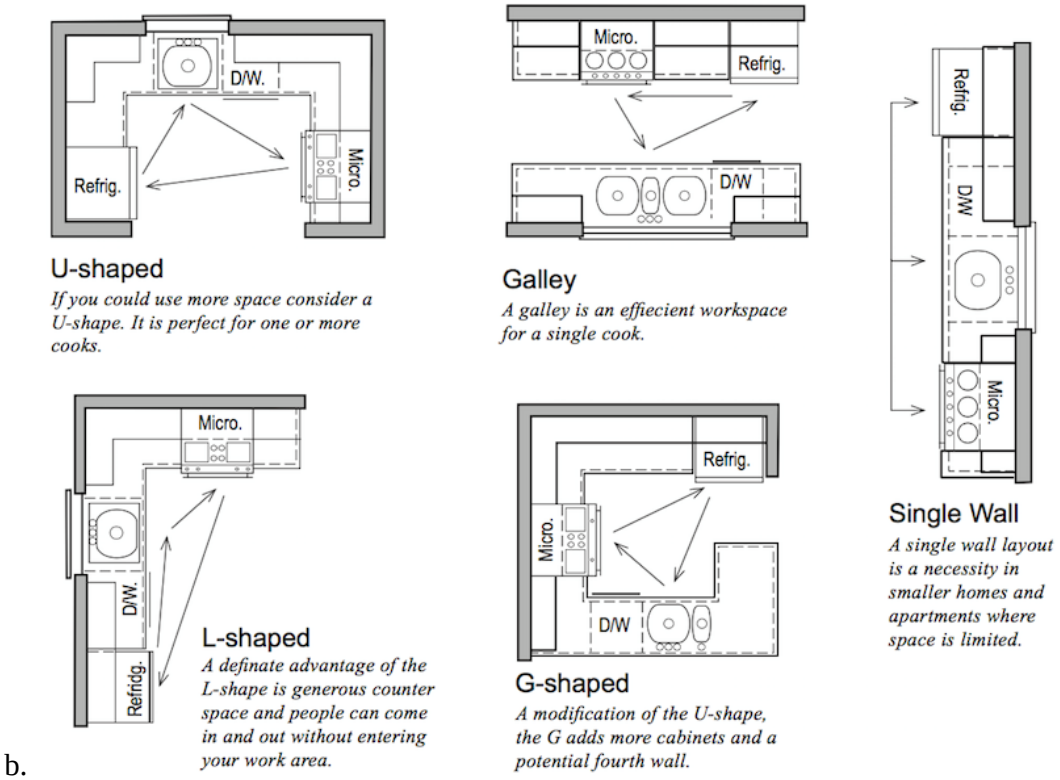


Figure 2: Basic kitchen layouts a.[10], b.[11]

Otl Aicher distinguishes four task categories with about 250 tasks that are performed in a kitchen: (1) preparation, (2) concocting, (3) cooking, and (4) arranging [12]. According to Aicher, if the main activity area requires little movements and provides enough space with immediate access, then cooking is best supported. He distinguishes three main activity areas: (1) preparation and concocting area, (2) cooking area, and (3) washing area. Preparation areas are provided by tables or counters, cooking areas by stoves, and washing areas by tables, sinks, and/or dish washers.

But is the kitchen work triangle still relevant today? The work triangle has been the golden standard of kitchen design for many years now and its appeal lives on. For a cook, having the three most important kitchen elements no more than a few steps away is as convenient as it ever was. The original functions described with the kitchen triangle still exist within the modern-day kitchen. The technology of the period was limited to just those three main areas in a kitchen, but there are several more small appliances to be considered today. Moreover, since the post-war period, kitchens have increased considerably in size, are frequently open to the rest of the home, as opposed to a closed-off space where everything happens behind-the-scenes tasks, and a long list of appliances is the standard. In modern times, habits and needs have changed. The kitchen is frequently used at once by two persons, and plays also the role of an informal meeting place for family and friends. In the early '90s, the National Kitchen & Bath Association [13] introduced the multiple rectangle concept - the idea being that the microwave or separate ovens were considered a fourth or fifth element, taking into account families who didn't always eat together and the assumption that there might be multiple cooks. Today, we are more demanding from our kitchens than when the triangle idea was invented. This means that the work triangle would need adapting. Treating the work triangle approach as a starting point and according to NKBA kitchen planning guidelines with access standards [14] work zones layers nicely onto the kitchen work triangle concept as a modern approach.

Instead of focusing on the distance between appliances, the zone theory divides up the kitchen layout by function, and each of these functional zones has everything you need for that series of tasks. Here is how it's commonly divided in five zones:

1) **Consumables Zone** — In simple terms, most grocery items are stored in this zone. This zone will house the refrigerator for perishable food items and cabinetry for non-perishable food items.

2) **Non-Consumables Zone** — An area for storage containers, dinnerware, glasses, etc. These items can be stored in wall or base cabinets. Consider using plate holders to store dinnerware inside of drawers.

3) **Cleaning Zone** — An area for waste, recycling items and cleaning products. The sink and dishwasher should be located in a cleaning zone. In general, the dishes and glassware located near the sink and dishwasher. Food storage, such as zipper bags and reusable containers are near the sink. Adding pull-out garbage cans or recycle bins are practical solutions for cleaning up after meals or parties.

4) **Preparation Zone** — An area for food preparation. Keeping cutting knives and utensils in a drawer near the preparation zone. Knife blocks and utensil trays are located in the preparation zone in order to keep these items organized and easily accessible. Storing mixing bowls in drawers or rolling-out shelves so as not to be forced to reach the back cabinets.

5) **Cooking Zone** — An area for cooking. Pots and pans, casserole dishes and cooking utensils should all be stored close to the cooking zone. Spices and oils are near the range. Storing these items in drawers with dividers to make cooking tools easy to find and accessible.

By placing the zones in the order listed above, an assembly line of meal production is formed. Food staples get carried to the prep area for cooking. Pots and pans are close at hand. And the dishwasher is right next to the silverware and plate storage.

One downside is that for bigger kitchens, every one of these zones winds up being huge to the point that it pulls the three significant kitchen components (cooktop, refrigerator, sink) excessively far separated to be convenient. For instance, to place the refrigerator and large walk-in pantry right next to each other, you might need to put both far away from the sink, creating the annoying need to walk five paces from the refrigerator to the sink, just to grab some ingredients and wash it.

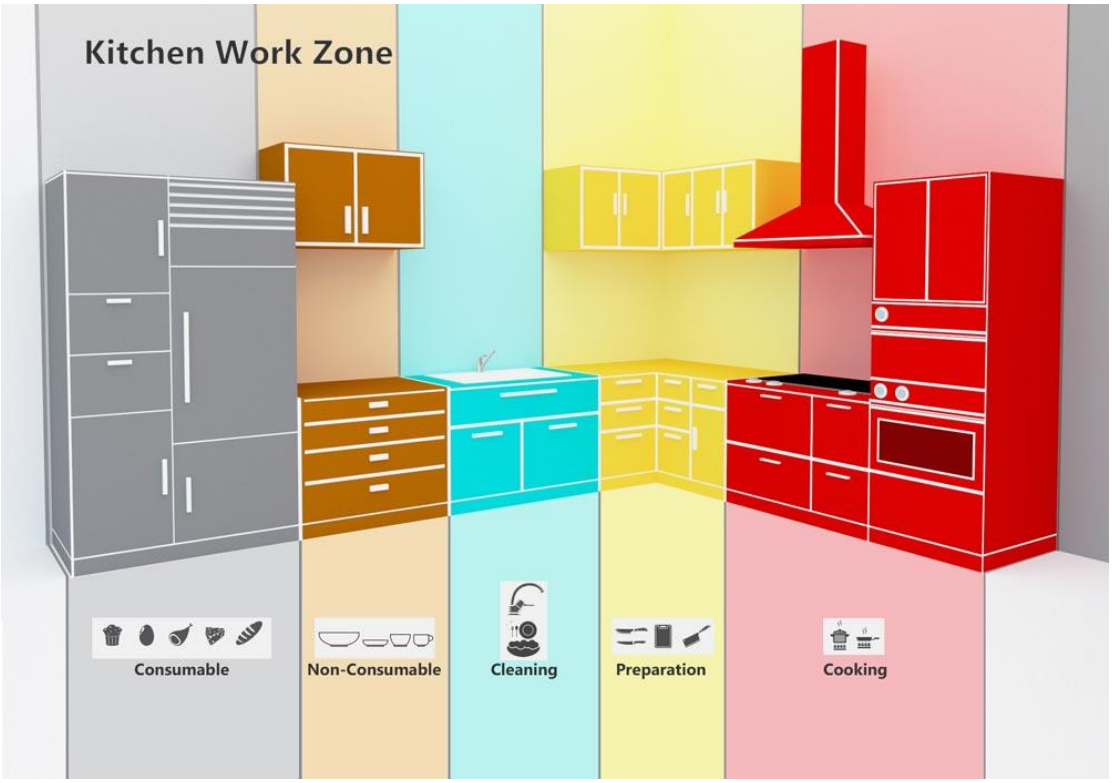


Figure 3: Kitchen work zones [15]

Other kitchen zones

Other authors have extended the zone concept away from the five core work zones mentioned above. Here are just a few of the countless zones which might be encountered.

- Entertaining zone (bar ware, liquor, mixers, serving trays, napkins, coasters, etc.)
- Holiday zone (decorations, vases, candles, fine silver and crystal, etc.)
- Small appliance zone (food processor, juicer, griddle, slow cooker, pressure cooker, blender, etc.)
- Hot beverage zone (coffee, tea, cups, saucers, coffee grinder, sugar, etc.)
- Medication zone (daily medications, vitamins, first-aid)
- Homework zone (desktop surface, laptop, files, pens, etc.)
- Family hub zone (Mail sorting and drop zone, takeout menus, calendar, etc.).

2.2 Complexity of the cooking process

Cooking, cookery or culinary is both an art and a science, and by its narrow meaning the term indicates the technique of using heat to prepare food for consumption, while by the widest, the set of processes by which the transformation of certain plant and animal materials into food is achieved, as well as its serving and styling.

The ability to prepare and cook food to eat is considered an essential activity of daily living (ADL), although over the last decades it has increasingly become a diverting time in addition to a necessary daily task [16]. Cooking can be a social event, but it is an individual task as well most of the times. Cooking techniques and ingredients vary widely across the world, from grilling food over an open fire to using electric stoves, to baking in various types of ovens, considering environmental, economic, and cultural traditions and trends. The cooking process can be performed by home cooks, as well as professional cooks and chefs in restaurants. It can vary and is related to the experience and the skill level of each cook.

Cooking process, is a combination of cooking recipes, cooking actions, cooking objects and devices that have to cooperate together and make a cooking result ready for consumption. There is a high level of complexity in this process due to the different recipes given by the different authors in not a formal way, a huge variety of different cooking methods, a plethora of cooking ingredients, cooking utensils and devices. Except of the existing utensils and devices, every day are inventing brand new for performing every single cooking action effortless and/or offer time saving [17]. A qualitative study involving thirty cooks and investigating domestic cooking, including cooking skills, revealed useful insight into people's cooking practices and approaches through interpreting cooking skills as complex (consisting of mechanical, perceptual, conceptual, academic and planning skills) and 'person-centred', irrespective of the kind of food cooked with – pre-prepared, fresh or raw ingredients or of how contemporary kitchen technology routinizes or changes cooking skills [18]. Singleton [19] points out that all practical tasks require a combination of mechanical abilities, academic knowledge and 'tacit' perceptual, conceptual and planning skills.

According to [20],[21] dimensions such as confidence, attitudes, behaviour, and application of individual knowledge are involved in perform cooking tasks that range

from planning menus and shopping to food preparation of unprocessed, minimally processed, processed or ultra-processed foods (Figure 4).

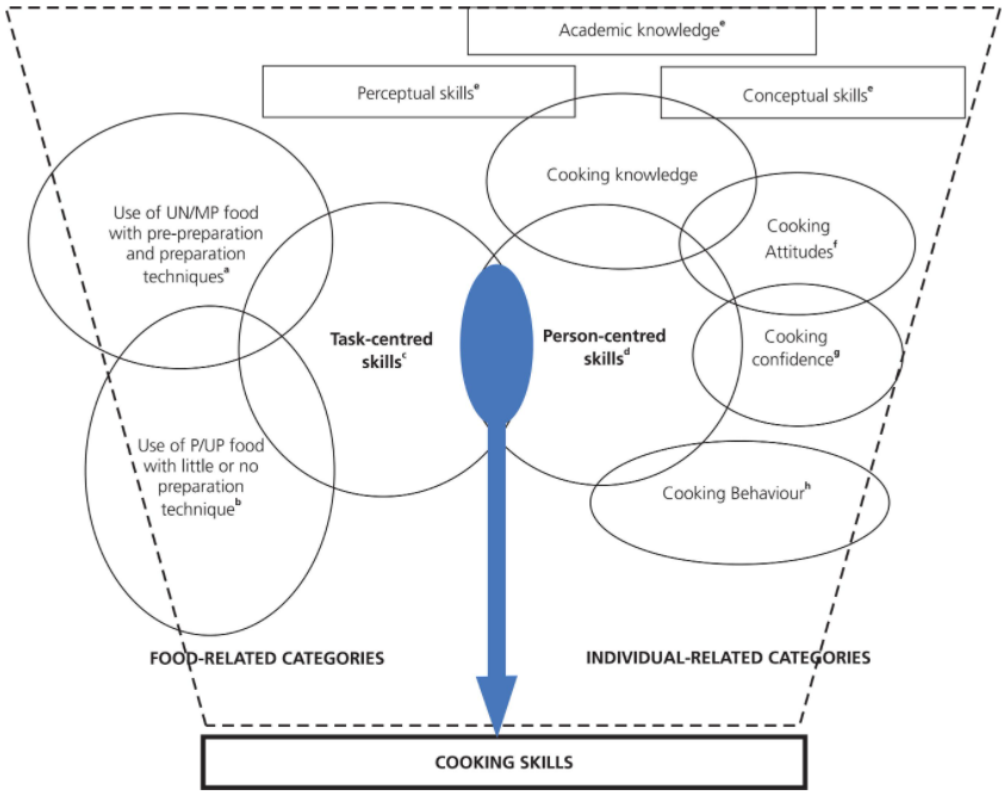


Figure 4: Conceptual model of cooking skills, according to categories related to foods and individuals [20].

First of all, every cook has to deal with various recipes. For the selection of a recipe, the cook matches available ingredients with recipes, discovers the missing ingredients and selects alternative recipes or alternative ingredients. Cooking situations are typically characterized by some planned behavior that follows scripts described by recipes. These recipes are just remembered by individuals while other recipes are externally documented in books, on notes, or by digital media. Earlier recipes often included much less information, serving more as a reminder of ingredients and proportions for someone who already knew how to prepare the dish. Modern culinary recipes normally consist of several components. The field of recipes has occupied the scientific community as a knowledge representation area, as well as a time and accuracy optimization problem [22],[23].

A lot of cooking methods and techniques exist. These include baking, roasting, frying, grilling, barbecuing, smoking, boiling, steaming and braising, etc. More methods are added with the invention of new devices, such as microwaving. Various methods use differing levels of heat and moisture and vary in cooking time. The chosen method affects the end result because some methods are more appropriate to some ingredients than others. In order to complete these cooking methods effectively, cooks either must have this knowledge in advance or must figure it out [24].

During the cooking process, a cook has to face an abundance of cooking ingredients, arrange their portions and prepare them effectively. Demas [25], for instance, in describing the cooking skills acquired by children who took part in her interventionist cooking and food choice study, refers to 'estimation skills' - an ability to estimate quantities of ingredients that come with experience. There are specific preparing and chopping techniques for the ingredients, as well as various ways of preparing devices and utensils which are related with specific ingredients, for instance a paring knife for vegetables and a specific meat knife for meat.

Cooking equipment is another huge chapter in the cooking process. There is an abundance of cooking utensils and devices cooks are not familiar with. The appliances, despite their automation, rarely provide feedback on their status or prompt users for interaction. Cooking equipment is inherently connected with what people cook, how they cook and their desired result, and consequently the cooking skills and knowledge involved [26].

Many people regularly multitask while cooking at home. Juggling household chores, reusing limited kitchen utensils, and coordinating overlapping cooking times for multiple recipes can cause frequent task switching and simultaneous task monitoring while cooking [18],[27]. Cooks searching for a particular cooking utensil or ingredient must sometimes conduct a sequential search within cabinets. Sequential search is wasteful since its span is inefficient relative to the quantity of things being searched.

As a result, the cook occasionally loses track of his cooking progress especially when determining which ingredients have already been added, counting multiple scoops of an ingredient, and keeping watch of cooking times. Engelkamp [28] reports that we may be unable to recall self-performed actions due to routinized actions of everyday

life that happen automatically without conscious awareness, from memory issues due to aging, or from uncertainty between an already performed action and an action which there was intention to be performed. Interruptions are more disruptive the more they are similar to the interrupted task, the more complex they are, and the more time they consume [29]. All of the above consists a complex cooking process which reveal several aspects potential research.

2.3 Cooking Evolution – From Traditional to Digitalized

Preparing food with heat or fire is an activity unique to humans. It may have started around 2 million years ago, though archaeological evidence for it reaches no more than 1 million years ago [30]. According to [20], since ancient times Hippocrates' nutrition principles have predominated the field of cooking and the main goal was to make the food digestible and foster good health. The next centuries cooking food gain more gastronomical and nutrition aspects. High gastronomy and culinary art were found in the mid-1600s. During the 1920s, new technologies, such as ice-box, electrically powered mixers, cleaners and stoves began to be used widely. By the mid-20th century, there were thousands of cookery and recipe books available.

The next revolution came with the introduction of TV cookery programs. TV cookery programs brought recipes to a wider audience. In the early days, recipes were available on television.

In the early 21st century, there has been a renewed focus on cooking at home due to the late-2000s recession. Television networks, such as the Food Network, and magazines are still a major source of recipe information, with international cooks and chefs having prime-time shows and backing them up with Internet websites giving the details of all their recipes. These were joined by reality TV shows, and many websites offering free recipes.

Today, there are plenty of websites and apps that offers an abundance of free recipes and aids to support the process of cooking, such as meal planners and pantry ready recipes. Other platforms aim to help people with healthy nutrition and offer records about their diet and suggest cooking recipes related to their goals. As a last addition, five years ago robotic chefs made their appearance. Moley Robotics [31] has created the world's first fully-automated and intelligent cooking robot. A pair of fully

articulated robotic hands now reproduce the entire function of the human hands with the same speed, sensitivity and movement.

2.4 Smart appliances and the Internet of Things

Over the past years the Internet of Things (IoT) has developed, with high potential of increasing comfort and quality of life. The term Internet of Things (IoT) refers to an abundance of physical and virtual "things" that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the Internet [4]. Steadily, the IoT becomes a part of daily life and we can meet the related technologies in various domains, such as intelligent homes, healthcare, transportation, security, etc. The Intelligent Home is integrated with such devices and smart objects for lighting, heating, air conditioning, TVs, computers, entertainment systems, large home appliances such as washers/dryers and refrigerators/freezers, security and camera systems capable of communicating with each other and being controlled remotely by a time schedule, phone, mobile or internet [32], [33]. Among emerging technologies for the home are smart kitchen appliances. Actually, smart kitchens appliances market was worth US$476.2 million in 2013. and is expected to soar at a CAGR (Compound Annual Growth Rate) [34] of 29.1% to 2022, to be valued at US$2,730.6 million. The success of smart kitchens is attributable to the fact that this tech improves nearly every aspect of cooking. For instance, smart portable devices such as mobiles and tablets can support the cooking process through easy access to recipes with instructions, cooking tips, recipe reviews, multimedia, etc. Moreover, smart kitchen appliances can help reduce waste. These appliances come equipped with features such as self-cleaning or waste sorting. They can help users cook better using smart ovens, scales, and thermometers which allow users to measure and monitor cooking [35]. Smart kitchens can support healthier cooking through devices which can monitor food ingredients for allergens, or have connected fitness technology, which enables users to monitor and synchronize food consumption with fitness routines. They also provide automatic shut-off of appliances such as ovens, preventing the risk of fire. As an example, a smart oven can connect to apps that provide cooking tips. Inventory applications tracks how long items have been in the refrigerator and notifies the user when they are nearing their expiration date. Smart egg tray assists in racking each egg and the duration of time that it can be consumed. The HAPIfork system [36] monitors

how many bites of food one takes and at what rate. If over stuffing of the mouth is made happens than one bite every 10 seconds the fork warns by vibrating to slow down the intake. Drop [37] is a smart kitchen scale designed to prepare beautiful and delicious food without any experience. In this device the scale is connected to a custom iPad application via Bluetooth.

2.5 Ambient Intelligence in the Kitchen

AmI environments are designed based on a user-centered approach, aiming to anticipate user needs and support sensibly and proactively people's everyday life [38], [39]. Transforming the traditional kitchen into an AmI environment could potentially have significant positive impact on cooking skills, self-confidence, safety and performance of the residents in the cooking process. Inside an Intelligent Kitchen, activities are enhanced through the use of pervasive and mobile computing, sensor networks, multimedia computing, middleware and agent-based software [40]. Additionally, commercial artifacts such as smart refrigerators and ovens have gained popularity and have become major tools in the kitchen. However, the proliferation of ICTs raises the need of making human-computer interactions natural and transparent to the users, thus helping them to focus on the cooking process with the support of the technology, and not being distracted by the apparent complexity of technology [41]. It is also important to integrate technology invisibly to avoid potential damage by heat or liquids [42].

In case of an Intelligent Kitchen, the preparation and concocting area is defined by a counter with a Tangible User Interface (TUI), and the Fishkin's two dimensional taxonomy which uses metaphor and embodiment as its two axes is taken into consideration [43]. As residents often multitasks through parallel cooking processes, user attention is a rare and precious resource. So, the design of multimodal interfaces for cooking assistance systems should consolidate the actions into the user's context [44]. The availability of information in a certain sense must prevent the attention of the resident from other activities, that are currently irrelevant. This must also consider the different characteristics of modalities such as vision or hearing. While vision is the dominant conscious sense, it features a narrow focus of attention which can be self-controlled, meaning that people can voluntarily look in any direction easily, but there is strong evidence that processing time of auditory information can be shorter than visual. The human sensory system can process auditory information instantly without

interfering with visual feedback processes, and regardless of the visual channel stimulus. While the visual channel allows for creating previsions of approaching events and detection of changes in any dynamic environment, the use of the auditory channel and its combination with the visual can enhance perception and learning [45], [46]. Moreover, people are increasingly using various devices daily and, in many cases, these devices need to work together in a seamless manner towards achieving the same goal, a term known as cross-device interaction [47] and this can apply to the smart kitchen as well due to the devices that need to be interconnected such us timers and ovens. Regarding systems that have the ability to migrate amongst various devices, Rowland [48] wrote that it is not sufficient to design individual User Interfaces (UIs) for each device in isolation, designing for Distributed User Interfaces (DUIs) [49], [50]. The top priority should be to create a coherent understanding of the system, as well as a solid intercommunication between devices. Wäljas et al. [51] define three key concepts for cross-platform service User Experience (UX), which together ensure a coherent experience:

Composition refers to the way the functionality of a service – especially the user-facing functionality – is distributed across devices. Good composition distributes functionality between devices to make the most of the capabilities of each device. Designers should consider the context in which each device will be used, and what users expect each to do.

Consistency works to create a sense of coherence of the overall system. It is important to make the devices look, feel and sound like a family so that users form a clear mental model of the system and its capabilities.

Continuity refers to the flow of data and interactions in a coherent sequence across devices. The user should feel as if they are interacting with the service through the devices, not with a bunch of separate devices.

Since nowadays Intelligent Kitchens contain a wide range of technologically augmented artifacts, a mechanism that transforms the kitchen into a unified environment rather than a group of isolated units, respecting the concepts of Composition, Consistency and Continuity is of outmost importance, and AmIChef aims to deliver such an experience.

Chapter 3
Related Work

Many attempts have been made to provide systems which assist the user in the culinary process, both a research and an industrial level. However, few of them have tried to offer a cooking experience similar to the actual cooking assistance during the cooking process, and even less take advantage of what Ambient Intelligence has to offer.

3.1 Literature Review

Cook's Collage [52] realizes a recipe tracking service through a video-based approach. If a cook interrupts his/her cooking, they will be provided with a memory aid in form of a video summary of what they have already done. More precisely, the user has access to images which show the last 6 actions and receives information about which ingredient are used and in what quantity with respect to the order of the performed actions. An embedded camera above the preparation area records the user's actions. In stress situations, memory aids such as video and images has proven helpful according to this work (Figure 5).

CookTab [53] is a smart cutting board which allows a user to easily record their cooking activities and provides visual and auditory feedback. Many homemade meals, which are modified to suit the family's tastes, are not written down as recipes and CookTab provide this opportunity to users in the form of recordings their actions. The system focusses on the ingredients that a recipe needs, and more precisely on a recording system while the cutting action is taking place. It records details such us name and weight of the ingredients. The system has limited functionality insofar it is able to support cutting actions on a specific technology-enhanced cutting board (Figure 6).

Figure 5: Cook's Collage [52]

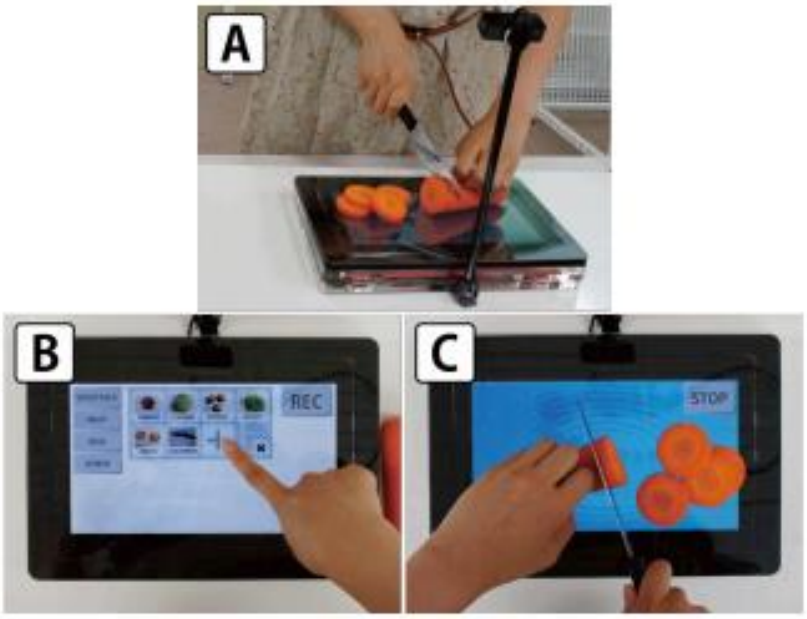
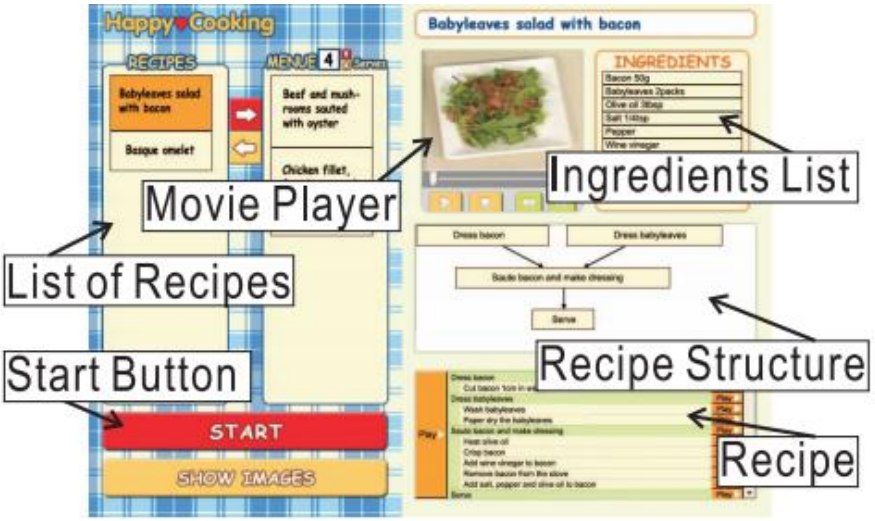


Figure 6: CookTab smart cutting board [53]

Cooking Navi [22] is a cooking navigation system which helps a user to cook several recipes in parallel. To realize this, the system optimizes the cooking procedure considering the following restrictions: (1) Duration of cooking, (2) Accuracy of cooking, and (3) Learning effect, by providing appropriate instructions to users at the

right timing, making use of multimedia information. Regarding user environment data, users are requested to input their kitchen environment, the number of stoves, cutting boards, tables, sinks, and their layout. The system faces cooking as an optimization problem and uses an optimization algorithm for reschedule cooking multiple recipe. In the preliminary experiment that took place even novice cooks succeed in finishing the dishes' preparation. The system seemed useful for experienced cooks as well, but the experiment shown that the rescheduling algorithm that is performed in the cooking process might not be suitable for the artistic side of cooking (Figure 7).

a.



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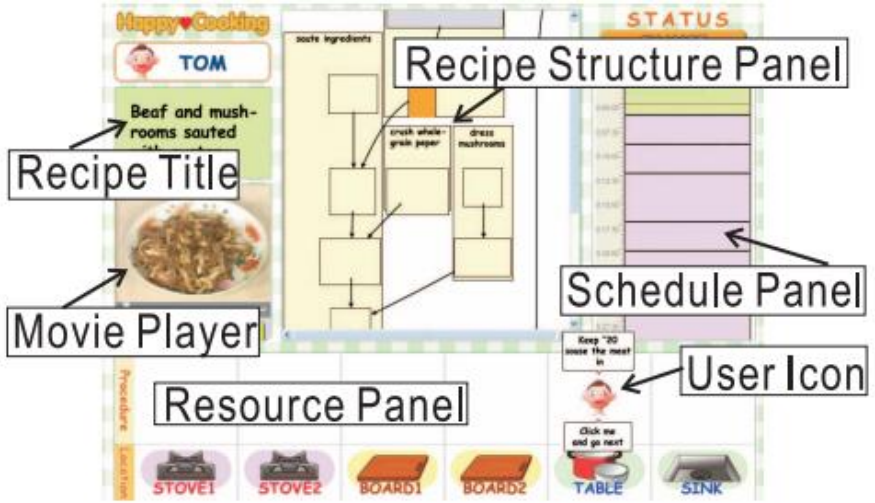


Figure 7: Cooking Navi navigation system a. Recipe Browsing Window, b. Cooking Navigation Window [22]

CounterIntelligence [54] can provide information to coordinate and instruct cooks on the use of the kitchen. It presents an augmented reality kitchen with five digital augmented systems that reveal the status of tools and surfaces in the space in order to enhance the kitchen experience. Information can be projected on nearly every surface of the space: the refrigerator door, range, countertop, cabinets, and faucet. The results of observation reveal that the cooks using the augmented reality system had a slight advantage over a control group in the location of items, and a slight disadvantage in the preparation of food. Moreover, video, photo or sound-based instructions along with text and graphics are not included which seems that could be a cue to examined.

a.

b.

Figure 8 : CounterIntelligence: Augmented Reality Kitchen [54], a. Virtual Recipe b. Augmented Reality Kitchen: information projection on the refrigerator (1), the range (2), the cabinet (3), the faucet (4) and drawers (5).

First-Person Cooking [55] is an interactive kitchen counter which supports hobby chefs with textual, visual, and audio information while cooking. It is based on a cooking television shows with the difference that users can playback the video and read the instructions of a recipe on demand. It aims to support the entertaining and social process of cooking. The user can adjust the depth of information for each step individually to their own experience and retrieve continuous feedback to check up on the success of their own results. This system misses a workflow suitable automation, such as tracking the progress within a recipe by object recognition and a possible connection to modern kitchen appliances (Figure 9).

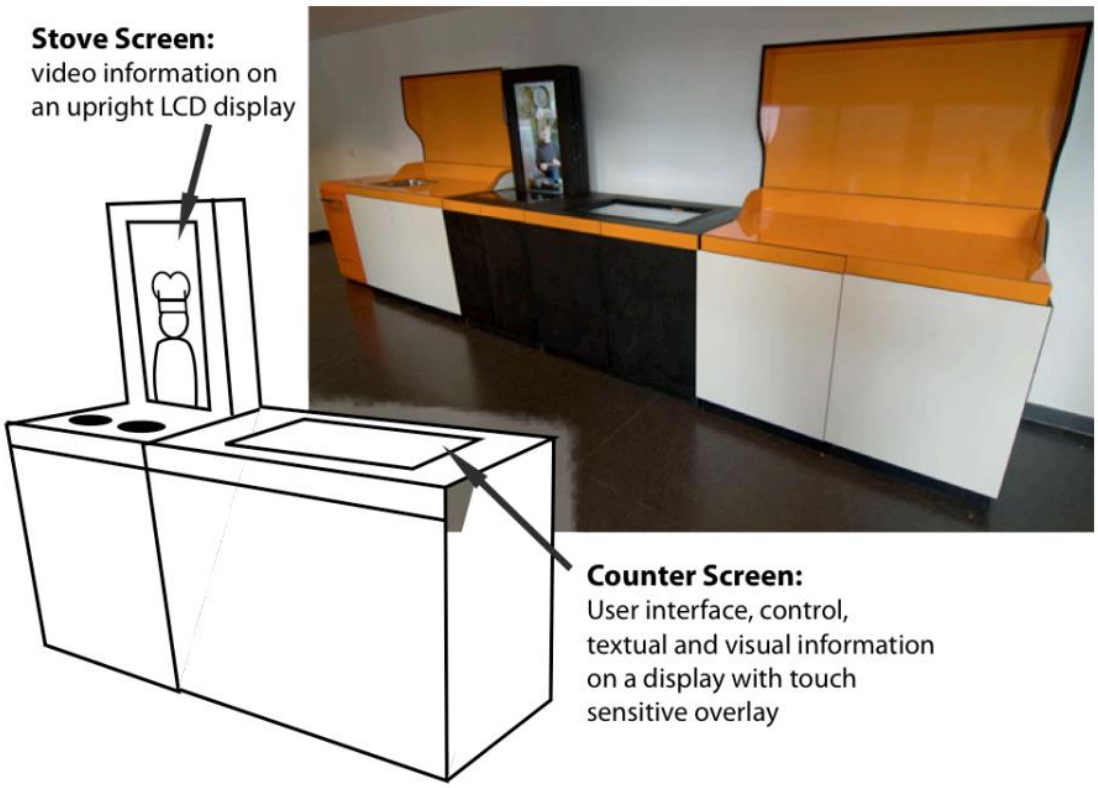


Figure 9: First-Person Cooking [55]

Kitchen AS-A-PAL [56] addresses human interaction with kitchen objects, both while performing activities and during inactivity. It uses RFID technology as a tracking method and a series of sensors for temperature, force/pressure, motion. It infers contextual information by the existence and the state of the objects on a surface. Three applications have been created.

- Interactive cookbook enhances cooking and baking experience by providing context-aware recipe recommendations on the mixing area of the kitchen. It guides the user through a recipe of their choice in the kitchen environment.
- Health'n shopping provides smart services for enhancing the user's shopping choices for maintaining health and be on a budget. They provide a list of objects store, an inventory level, smart searching, expiry control, shopping list with price information and nutritional value for the ingredients.
- Kaffe, god morgon is a smart phone application for controlling a coffee machine that can automatically prepare coffee. The application facilitates setting-up alarms, and the snooze feature.

No quantifiable user-based evaluation results are reported (Figure 10) .

Figure 10: Kitchen AS-A-PAL Interactive cookbook [56]

"KogniChef" [57] is a smart and interconnected kitchen environment and software framework that implements a cooking recipe. Based on a formal recipe description, the system can progressively produce a UI that is specific for the kitchen arrangement and guides the user through the recipe. They wish to support users with a series of interactions concepts. They wish to guide and teach users through the cooking process with helpful personalized information related to the user profile, as well as providing assistance to elderly people. KogniChef also monitors and controls actual physical

kitchen appliances, sensors and devices in order to retrieve contextual information. During this process, assistance modules are triggered, for example a versatile hob control, a stirring detection which is integrated into the workspace and a filling detection based on computer vision. They have also a kitchen related hardware setup. It consists of a main and a side unit. The main unit includes a working area with an integrated induction hob, a 4 K-screen as a backsplash wall which reaches an extractor hood, a short distance projector and a multi-camera array.

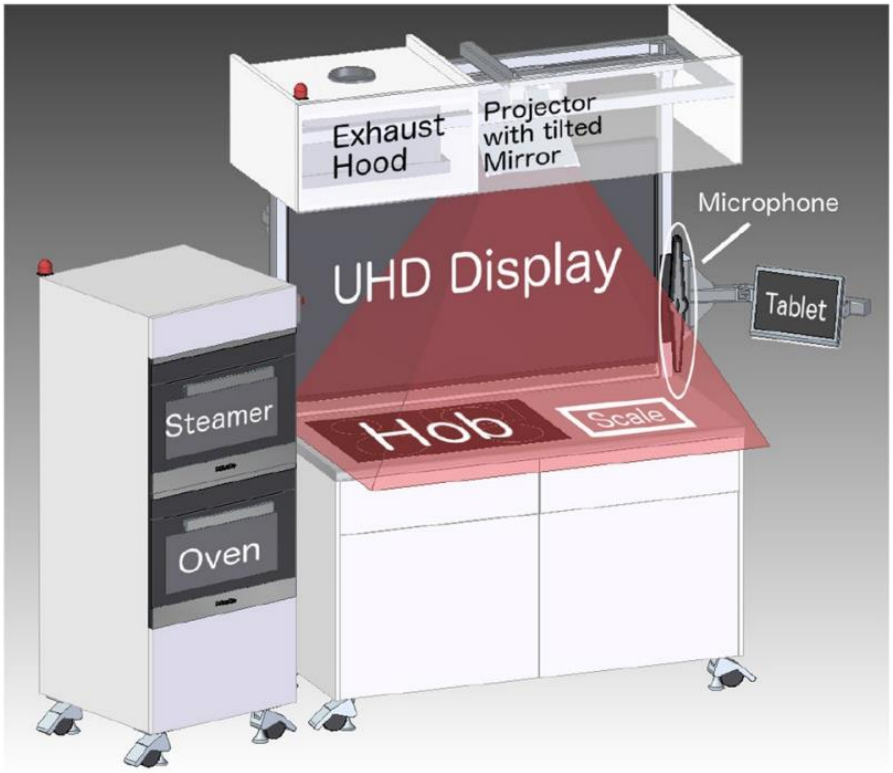


Figure 11: Key components of the KogniChef hardware setup[57]

The central communication hub is a tablet PC that is attached to a custom-designed side-arm, mounted to the right of the screen. In addition to a microphone array, there are integrated custom-designed four-point scale sensors into a small dedicated area of the worktop, as well as into the hob, in order to facilitate weighing and physical interaction detection. The side unit is a standard cupboard that contains an oven and a steamer (Figure 11). In its current state, the system can track the progress of an abstract recipe representation. So far, it has been tested with two recipe examples. During an early usability study in 2015, conducted with 12 participants, KogniChef was generally perceived positively. However, the study revealed several interaction obstacles, such as

erroneously interpreted hand gestures and visibility issues with the large back-screen that often required the user to step back to see the whole content. Due to these findings, the main graphical user interface was redesigned and relocated to the tablet control hub.

MimiCook [58] embodies a recipe in a real kitchen counter and directly navigates the user. It displays step-by-step instructions directly onto the utensils and ingredients, and controls the guidance display in accordance with the user's situations. This enables users to act intuitively and avoid wrong usages of ingredients and utensils. The system is able to support cooking guidance and recognize a particular cooking situation on a kitchen counter. The system consists of a computer, a depth camera, a projector, and a scaling device. The results of a user study shows that the participants found it easier to cook with the system and even subjects who had never cooked the assigned recipe did not make any mistakes. However, the system needs to be improved to better explain what to do with ingredients (Figure 12).

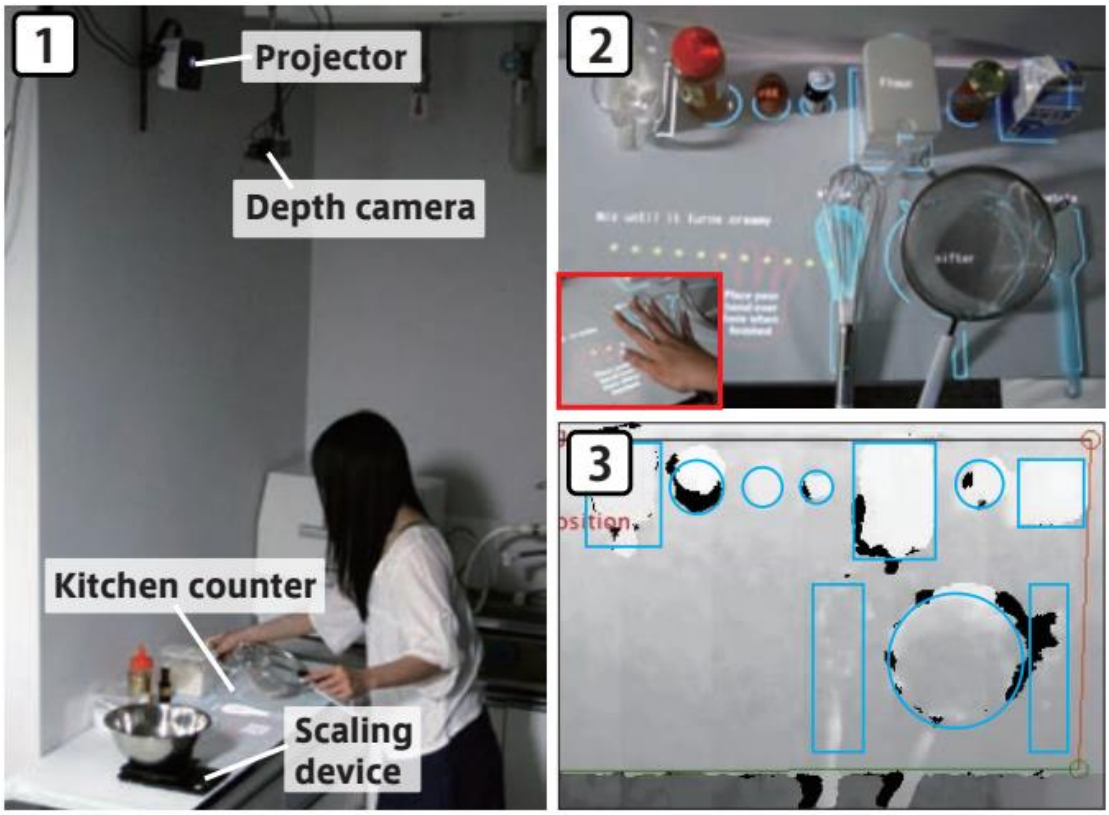


Figure 12: MimiCook cooking system [58]

Panavi [59] is a recipe medium that supports domestic users and concentrates on providing information about the movement and the temperature of the pan. Utilizing a

sensors-embedded frying pan—providing projected images, LED indications, and vibration—wirelessly connected with a computer system that shows text messages with sounds, the Panavi system analyses sensors' data, recognizes users' conditions, and provides the users with contextual instructions. Experimental results have revealed a difference between the understandings of instruction for each user group which consists of total of four beginner or intermediate level persons in three groups, because users had different experiences and cooking skills prior to the study. The system is able to support cooking conditions such as the temperature or movements. It is not clear how recipes are modelled beyond specific cooking sequence as steps (Figure 13).

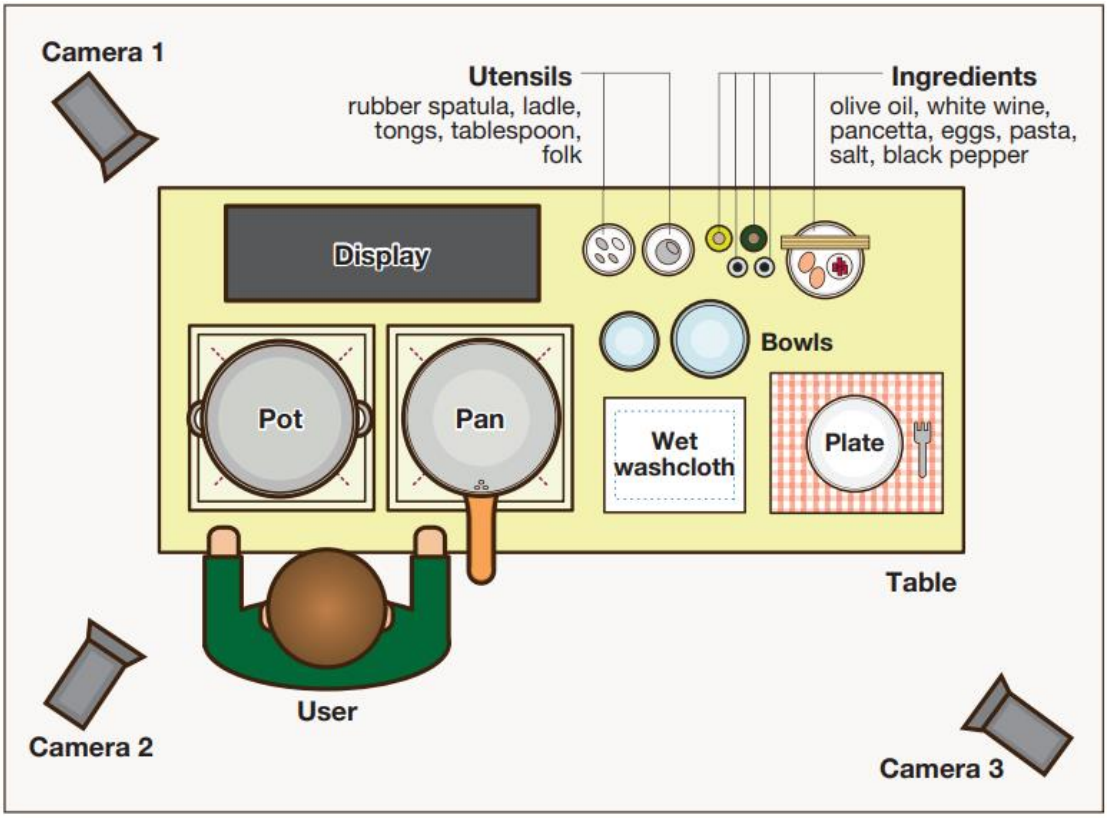


Figure 13: Panavi cooking system [59]

Smart Formulation Table [60] focusses on the counter area, supporting food preparation and concocting through non-intrusive information services that support weighing and mixing tasks. Moreover, it provides cooking related services such as a recipe retrieval service, which retrieves recipes by considering ingredients already placed on the preparation table and informs the cook for each recipe for which ingredients are missing. A semi-formal tagging system is provided by microformats that knows the hrecipe schema which encompasses attributes such as ingredients,

instructions, and duration of a recipe. Ingredient descriptions referenced by a hrecipe instance are used for comparison with available ingredients. Another available service is the recipe tracking service, which helps a cook to keep track of the next step. A third one is the ingredient identification service, which aids the user to identify an ingredient by markers. Finally, the alarm service indicates if an inappropriate ingredient is taken from the formulation table. The system includes a kitchen related hardware setup which contains a formulation table with integrated scaling mechanism. This study is limited to the formulation table function.

Figure 14: Smart Formulation Table [60]

3.2 Commercial Cooking Applications & Websites

Plenty of websites and mobile applications are engaged with the cooking process through recipe sharing, recommendation, representation, meal planning and other cooking related options for the user. The most popular of them are highlighted below.

Allrecipes [61] provides plenty of categorized recipes with details, multimedia, ingredients and directions. It is a kind of social media for recipes, where users can create their own profile, their own recipes and follow other users. It provides also a personized view for the recipes based on users' dietary preferences. Users can rate the recipes and leave reviews about them. A shopping list is also provided to users which they can manage manually. There are also articles with a variety of recipes with author's comments and tips.

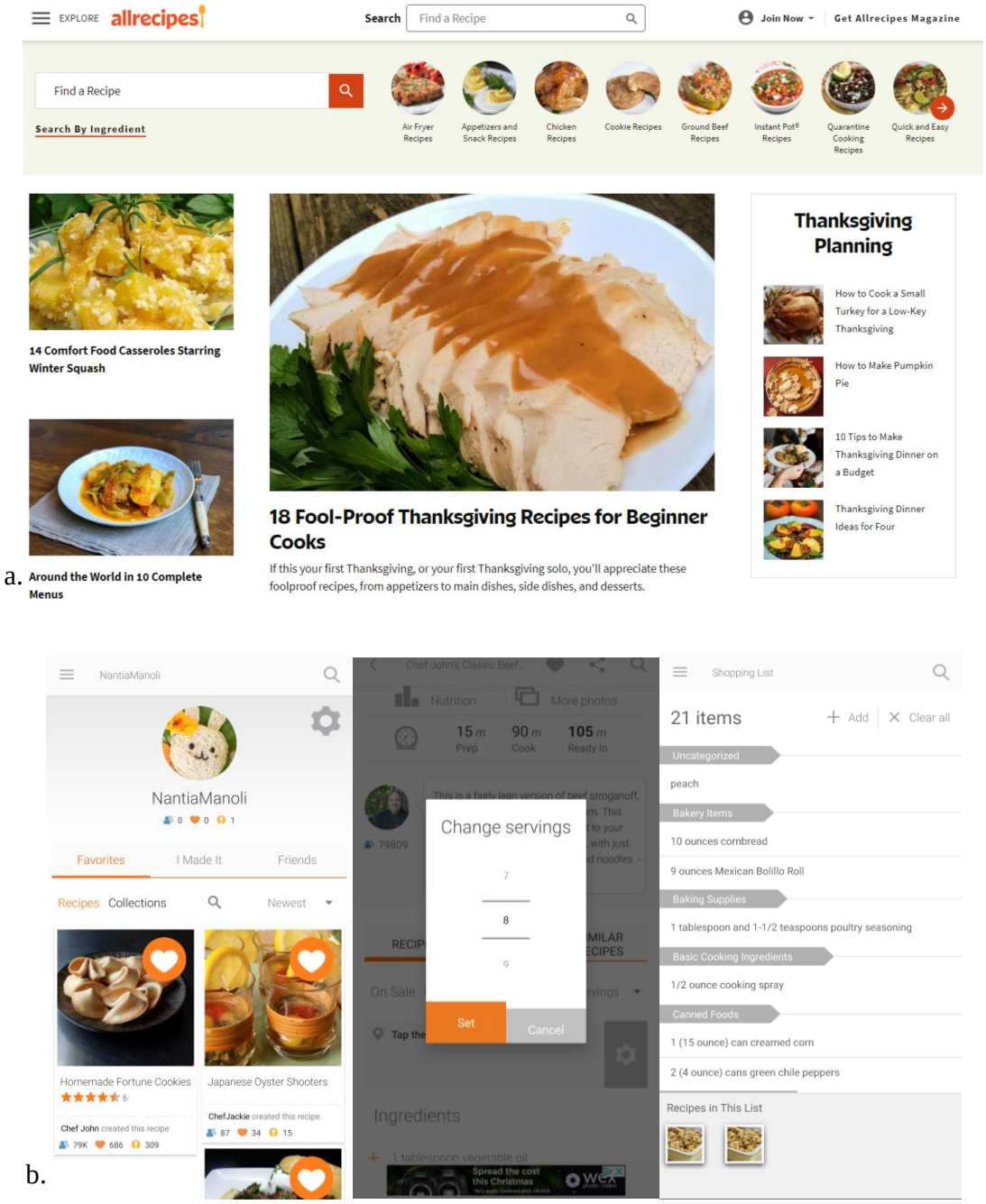


Figure 15: Allrecipes a. Website recipe browsing and b. Mobile application - favourite recipes, manually changing servings and shopping list [61]

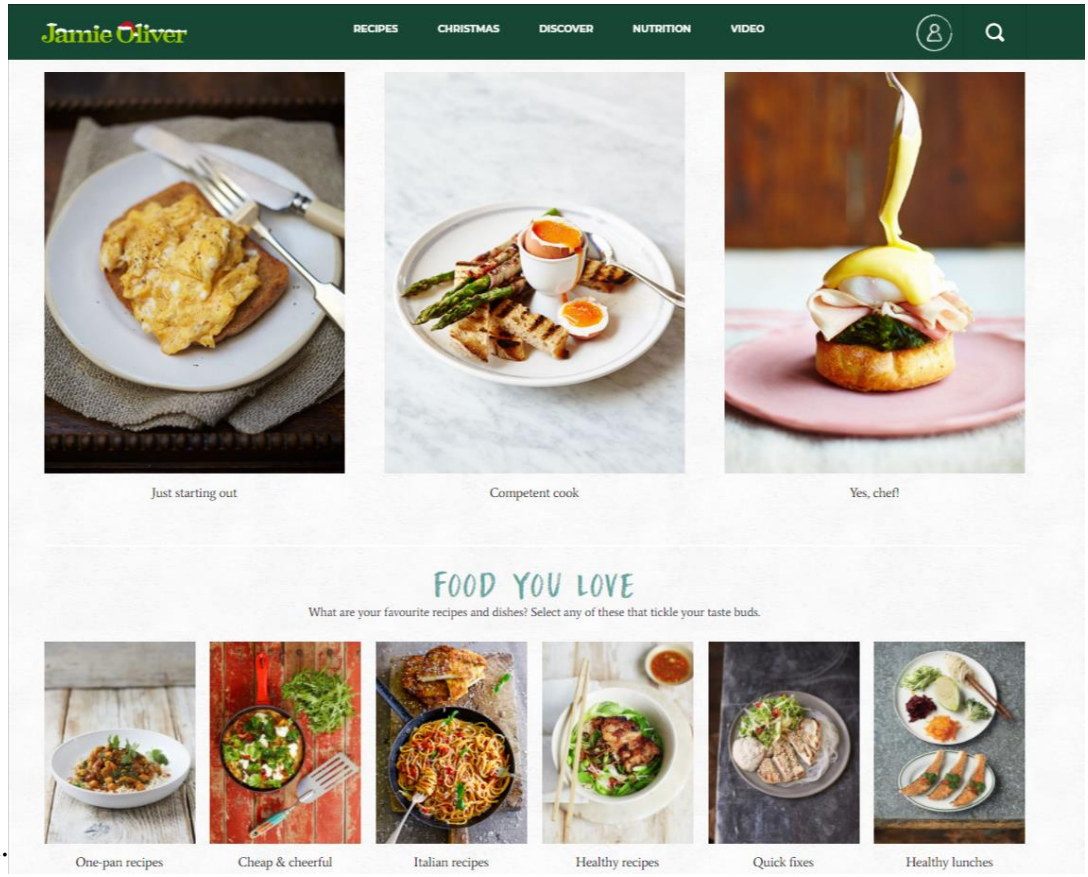
Cookpad [62] provides a plethora of categorized recipes in a website and an application. The registered users of this platform are the authors and creators of the cooking recipes. A user can create a recipe of their choice with the required ingredients,

method of cooking and images related to recipe and steps. Anyone can search these recipes and leave comments.

Figure 16: Cookpad website homepage[62]

Jamie Oliver [63] website and application platform provides a plethora of categorized and personalized recipes. There are plenty of articles related to the cooking art, as well as nutrition advice and tips. The platform supports numbered steps in the recipe method and the required ingredients. It also contains video recipes and an option for a shopping list according to a specific recipe.

a.



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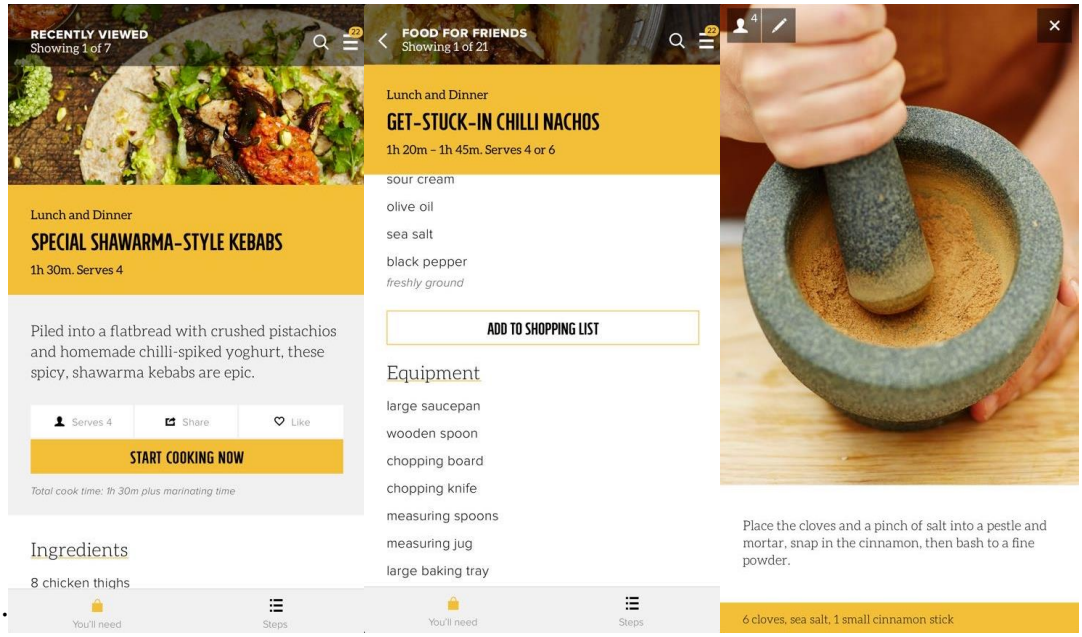
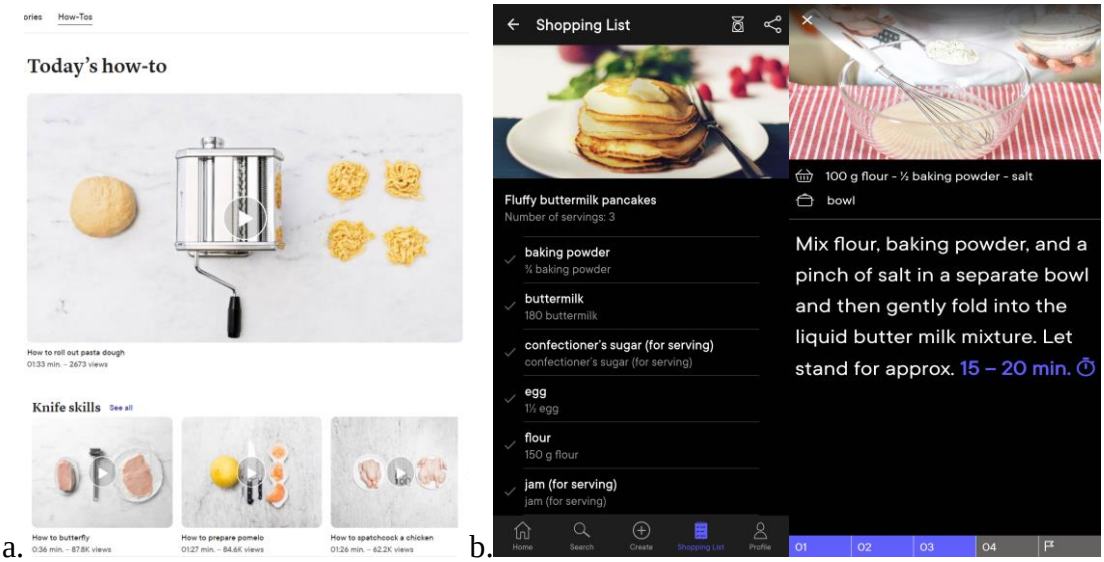


Figure 17: Jamie Oliver a. Website manually declaration of recipes b. Mobile application – recipe page, recipe related equipment, recipe step by step view with image [63]

Kitchen Stories [64] offers inspiring videos and photo instructions for recipes. It provides a website and an application running on various devices. It has recipe overview with details and recipe steps with cooking instructions, ingredients and utensils that are needed for the recipe step. It offers a way to the user for creating their own recipes and a recipe player in step-by-step mode with multimedia for ingredients and tools that are needed for the step. It supports the idea of a story which is a more extensive and descriptive way of representing a recipe from the point of view of the story writer, and the suggestion of two or three alternative recipes in the same story so the user can choose which one they will prepare. It provides an extensive categorization for recipes and How-To videos about cuttings methods and preparation of various ingredients. It also offers manual management of a shopping list related to the recipe.

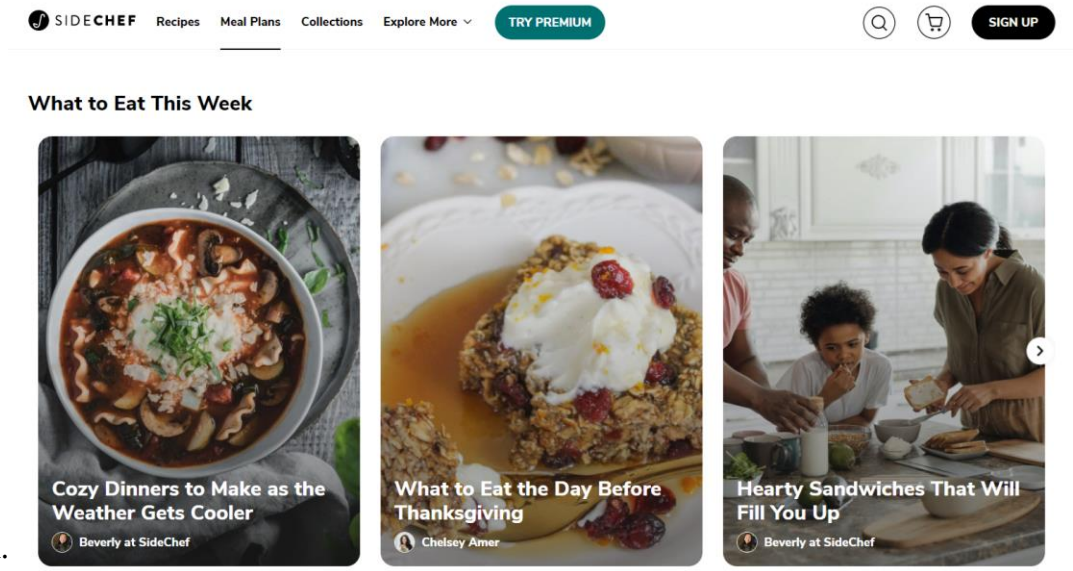


a. b.

Figure 18: kitchen stories a. Website how-to videos b. Mobile application – manually shopping list, step by step recipe guidance with images and timer option [64]

Side Chef [65] is a digital resource of recipes. It provides a website and an application for various devices. Through this platform the user can access a variety of suggested and categorized recipes with their details, rating and images of the recipe steps. It supports also a step by step mode with multimedia and list of ingredients that are needed in the step. Moreover, the user can explore a variety of articles about cooking, make his meal plan and browse collection of recipes. Finally, the user can manage manually their own shopping list and connect manually their available kitchen appliances (Figure 19).

a.



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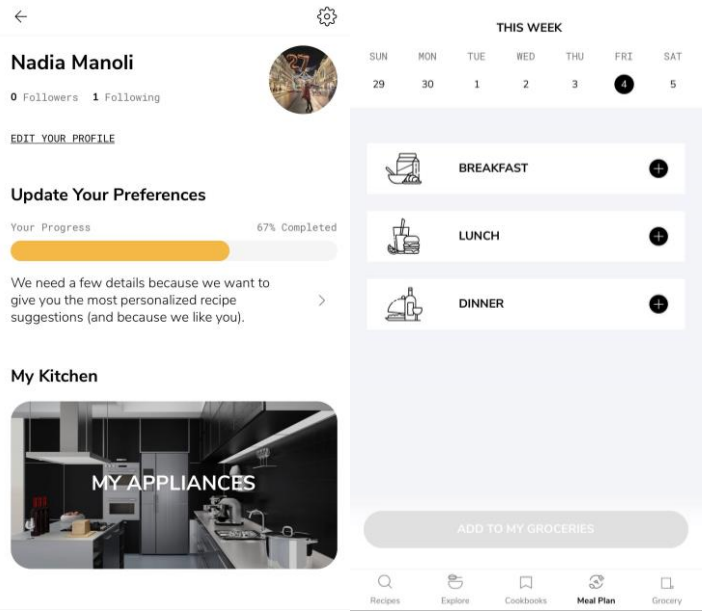


Figure 19: Side chef a. Website meal plan suggestions b. Mobile applications – manual connection with kitchen appliances, weekly meal plan

Yummly [66] is a smart personalized cooking sidekick which supports the cooking process through a website and an application for a plethora devices. It contains a variety of categorized recipes with their details, rating and directions on how to cook them. Moreover, it provides various of articles about cooking. Yummly supports a meal planner and pantry management through a manual shopping list. It also offers a step-by-step guided recipe feature which helps the user cook with short step videos, ingredients and utensils that are needed to complete the current step. It also introduces

a smart thermometer, a wireless meat thermometer with app-based cooking assistance, timers, and alerts (Figure 20).

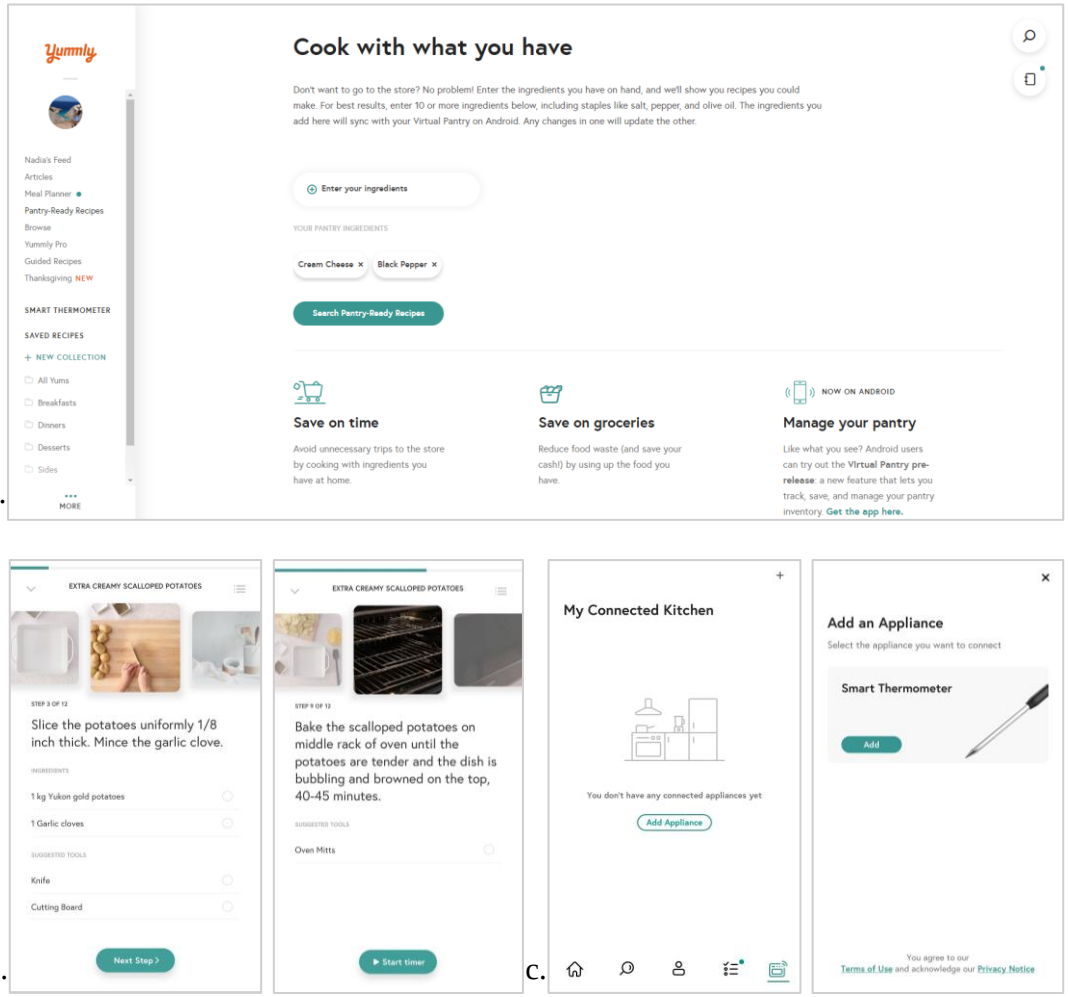


Figure 20: Yummly a. Website – manually managed pantry b. Mobile application – recipe step by step with related ingredients and suggested tools c. Mobile Application – connected kitchen appliances[66]

3.3 Discussion

The presented review of the literature and of industrial cooking applications has revealed several features that are supported by frameworks targeting the Intelligent Kitchen and the cooking process. The majority of the mentioned research systems focus on the actual cooking process and environment and the related equipment, whereas industrial cooking websites and applications approach in detail the planning aspect of cooking, including guidance. Few of them attempt a connection with smart appliances in order to aid the users. More precisely, the literature systems [22], [56] provide recipe browsing and personalized suggestions, as well as cooking guidance through user

interface. The works in [55], [57]–[60] provide cooking guidance through the recipe. In [22], the user have to insert their equipment manually although in [54] and [56] the kitchen is informed about the supplies of consumables and non-consumables. In [22], [57] structured recipes are used while [53] record manually the cutting actions.

Websites and applications [61]–[66] provide recipe sharing services and browsing in a plethora of categorized recipes. Some systems provide suggestions for recipes through personalized preferences which the user insert manually [61], [63], [65], [66]. Most of the systems [61], [63]–[65] permit to the users to manually adjust the recipe portions. Meal planning options on a weekly base are also provided [65], [66]. More precisely, [65] provides ready weekly plan meals, although custom made plan meals can be created [66]. The only platform that provides a meal history option that could be inserted manually by the user is [61]. Another planning option that is provided by most of the systems is the manual shopping list [61], [63], [64]. Furthermore, the systems in [65], [66] provide a connection functionality with a delivery service, in order to automate the process of shopping. Manual management of the pantry supplies is offered [66] and offer a pantry ready recipe suggestion to the users instantly. Recipe authoring is provided [62], [64] simultaneously with a cookbook in order to save them. A save option for recipes that the user desires to prepare later is also available by [61], [63], [64], [66] either on the cookbook or on favorites page. As far as the guidance aspect of cooking process is concerned, it is clear that commercial systems are short in comparison with the literature systems. None of them is able to provide personalized or situated guidance according to the skills or the preferences of the user. All of them provide a system interface with a step by step recipe, although the description of the steps does not provide a specific structure which is consistent for each step. The systems in [63], [64], [66] provide suggested cooking related utensils for each recipe. Additionally, all of them provide multimedia (image or video) for the recipe and the current recipe step. The systems in [64]–[66] provide appropriate timer setting in the related steps. Recent industrial systems attempt to approach the connected kitchen, by interconnecting the smart kitchen appliances in order to cooperate with recipe step by step mode that it is offered [65], [66].

In summary, the examined systems support the following features:.

A. **Cooking Planning.** Includes all actions that are required before the preparation of a meal: (i) browsing/ selection of the recipe, (ii) personalized suggestions (iii) recipe authoring (iv) configuration of recipes (v) planning meals (vi) provision of a cookbook or favorites recipes (vii) access the meal that are prepared at the past (ix) consumables and non-consumables management.

B. **Guidance-teaching.** Includes all aids that support, guide and teach a user through the actual preparation of the meal: (i) personalized guidance according to the skills and preferences of the user (ii) situated on the preparation area (iii) existence of multimedia (image and video instructions) (iv) step by step recipe instructions (v) presentation of required ingredients and utensils (vi) guidance through the kitchen environment (vii) real-time feedback on user and system actions (ix) recording of the process.

C. **Aware Kitchen.** Includes information that the kitchen should be aware of in order to support the user through the planning and preparation of a meal: (i) user profile (ii) tracking progress/ activity monitoring (iii) recipe state (iv) ingredients and utensils state (v) consumables and non-consumables state.

D. **Automated cooking - Kitchen appliances.** Connected kitchen appliances that the system controls.

E. **Distributed and multimodal user interfaces:** Provide distributed user interfaces through different displays thought the kitchen environment. This permits the information be distributed and situated along the kitchen when is required.

F. **Recipe Modeling (Modeling Cooking Activity)/ Cooking workflow.** Facilities for modeling a recipe and creating a schema with all the related modules that are needed to describe a recipe and the cooking workflow.

G. **Intelligent Kitchen as a hub for the Intelligent Home.** The Intelligent home is a context aware home that keeps residents' profiles and consequently contains information about residents' preferences, daily habits and schedule. This enables the intelligent kitchen to be an aware kitchen that operates as a hub for the intelligent home which means that residents can have access to the entire home control.

Table 1 presents the features that each of the studied frameworks support. As seen, there is no system able to cover all the above features. AmIChef aims to assist the residents multidimensional.

First of all, it intends to assist the resident both in the cooking planning aspect (A), as well as, in the actual cooking process in the related environment (B-G). It is clear that none of the related systems both literature and commercial are not combine those two dimensions completely. AmIChef supports the resident's preparation actions in order to be able to prepare a meal with browsing/ selection of the recipe, personalized suggestions of recipes, recipe authoring, configuration of recipes, planning meals. It provises, also, a cookbook along with favorites recipes saving, access the meal history and manage the consumables and non-consumables. It offers guidance and teaching through personalization according to the skills and preferences of the user on the preparation area with the existence of multimedia (image and video instructions) and step by step recipe instructions. It provides presentation of required ingredients and utensils through the kitchen environment. Moreover, real-time feedback on user and system actions is available.

AmIChef is a context aware system which mean that can use such information services from the Intelligent home to track the progress of the recipe and be aware of the ingredients, utensils, consumables and non-consumables state. It uses the connected kitchen appliances in order to control them according to the meal preparation state. All the information is distributed through the different displays in the kitchen environment and according to its location.

An important feature that was held is the recipe modeling and modeling cooking activity which produces a cooking workflow. Lastly, the kitchen as a hub was introduced which is a unique characteristic compared with the other systems which enables the intelligent kitchen to operate as a hub for the intelligent home which means that residents have access to the entire home control options.

● : Shows the percentage of the elements implemented for each category.

		A	B	C	D	E	F	G
Literature Review	**Cook's Collage** [52]	○	◔	○	○	○	○	○
	CookTab[53]	○	◔	○	○	○	○	○
	Cooking Navi [22]	◔	◑	○	○	●	○	○
	CounterIntelligence [54]	○	◕	◕	●	●	●	○
	First Person Cooking [55]	○	◕	○	○	●	○	○
	Kitchen AS-A-PAL[56]	◔	◑	●	●	○	●	○
	KogniChef [57]	○	◕	◕	●	●	●	○
	MimiCook [58]	○	◑	◑	○	●	○	○
	Panavi [59]	○	◕	◔	●	●	●	○
	Smart Formulation Table [60]	◔	◑	◕	○	●	●	○
Cooking Applications & Websites	**Allrecipes**[61]	◕	◔	○	○	○	○	○
	Cookpad[62]	◔	◔	○	○	○	○	○
	Jamie Oliver [63]	◕	◔	○	○	○	○	○
	Kitchen Stories [64]	◕	◑	○	○	○	○	○
	Side Chef [65]	◕	◔	○	●	○	○	○
	Yummly [66]	◕	◑	○	●	○	○	○
	AmIChef	●	◕	●	●	●	●	●

Table 1: Comparison between existing systems and AmIChef

Chapter 4
Requirements Elicitation

This chapter describes the requirements for the design of AmiChef, elaborated following a User-Center Design process (UCD) [67]. The Chapter initially introduces the design process, presents several motivating scenarios for this work and afterwards outlines the functional and non-functional requirements of the system.

4.1 Design Process

The process followed while designing the system was the Design Thinking methodology [68]. "Design thinking is a non-linear, iterative process that teams use to understand users, challenge assumptions, redefine problems and create innovative solutions to prototype and test. Involving five phases—Empathize, Define, Ideate, Prototype and Test—it is most useful to tackle problems that are ill-defined or unknown" [69]. In a series of meetings with several potential end-users (male and female users aged between 20 and 45 who have or not cooking experience), scenarios and personas were created for the 'Empathize' and 'Define' steps of Design Thinking (Figure 21).

Next, for the 'Ideate' step, multiple brainstorming sessions were organized, that produced a bunch of ideas, which were then filtered through interviews with domain experts (i.e. cooks, software engineers, technical installation experts). The participants approached cooking assistance from many perspectives and proposed many solutions. Some of them had to be excluded because they aim to automate procedures which would not really aid residents to actual prepare a meal. For example, a smart robot that supports the user in the cooking process was not our focus in this study. Experienced interaction designers also reviewed the ideas and offered valuable insights and comments, as well as preferences in regards to which ideas had the most potential in their opinion, in aspects of innovation and higher potential to be acknowledged by end-clients. Thus, the idea started shaping and the preliminary requirements were elaborated. During the 'Prototype' step, because of the multidimensional perspective of the

problem, the need of role playing as a prototyping method, emerged [70]. The very first user scenarios were created and several actors simulated the interaction with the system. The whole procedure took place in an experimental kitchen with paper props and artefacts (e.g. paper ingredients and utensils for the cooking recipe). The actors executed the scenarios, while two observers were taking notes of the whole procedure, including the comments and opinion of the actors.

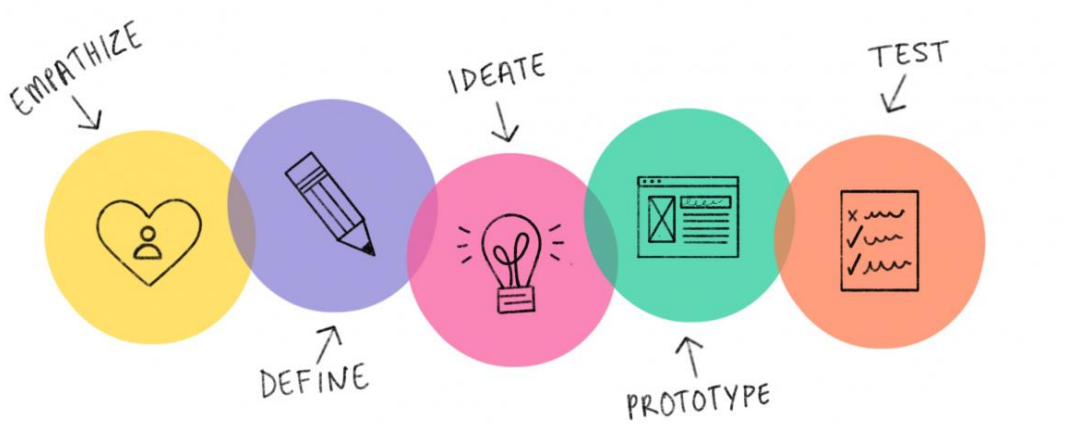


Figure 21: The 5 stages of the Design Thinking process [71]

This process came up with richer insights, ideas and creative solutions with no fear of judgment during it. The 'Prototyping' stage continued with low and high-fidelity prototypes for the most promising ideas. This was an iterative procedure, where design experts were involved to evaluate the prototypes before proceeding with the implementation. After several iterations on the prototypes, the development team undertook their implementation. Next, before proceeding with user testing, a cognitive walkthrough evaluation experiment of AmIChef was conducted with the participation of User Experience (UX) experts. The goal was to assess the overall concept and its potential, identify any unsupported features and uncover potential usability errors by noting the comments and general opinion of experts. Future work includes improving the system based of the findings of the cognitive walkthrough, and conducting a user-based evaluation in order to observe real users interacting with AmIChef and gain valueable insights.

4.2 Motivating Scenarios

Scenario building is a widely-used requirements elicitation method [72] that can systematically contribute to the process of developing requirements. Scenarios are characterizations of users and their tasks in a specified context, which offer concrete representations of a user working with a computer system in order to achieve a particular goal. Their primary objective in the early phases of design is to generate end user requirements and usability aims.

The following sections present a collection of envisioned scenarios where two users make two different recipes in the intelligent kitchen of their home. The main users of the system are the resident of an intelligent home, meaning it can be anyone regardless of gender or age. The system should support users ranging from people without any prior cooking experience to advanced skilled individuals.

4.2.3 Personas

In [73], three primary and three secondary cooking personas are studied during the cooking process. These personas share common behaviors depending on their needs. In our design we concentrated on one persona for each user category regarding their cooking skill ability, beginners and advanced users. The primary personas are beginners who need more guidance and support in the whole process, and the secondary cooking personas are advanced users who require more efficiency and time management support. The motivating scenarios shows a scenario case for each category.

- The **beginner user** makes their firsts attempts in the cooking area, to that end there is a lack of special abilities or skills. In order to accomplish the cooking tasks, beginners usually need specific guidance. One of the tasks for which they need guidance is the collection of the ingredients and utensils that are required at every step of the recipe. There is a possibility that the appearance of the required items is unknown for the users. Most of the times the actual cooking actions are unfamiliar to the users especially how to perform them. Beginner prefers the collection and weighting of the ingredients before they execute the recipe.
- The **advanced user** is a step ahead from the beginner. They usually have prior experience with the cooking process. They usually have executed the same cooking actions in the past, meal preparations and knows partially or completely how to

perform them. However they still need a recipe step sequence, the required ingredients with their quantities, multimedia about the recipe and time management support.

In the scenarios our users' houses are integrated with intelligent systems and smart devices for their daily assistance. In particular, their kitchens have a whole system that supports the management of their inventory and the cooking process. The equipment includes a kitchen wall display, a counter top display, and a refrigerator display, as well as ingredients and utensils inventories. Different functionality of the system can be accessed through various devices.

- **Beginner user**

  Jim is an undergraduate student at the Computer Science Department at University of Crete. We are during the COVID-19 outbreak, so he is staying safe at home with his sister, who is also a student of Physics.

- **Advanced user**

  Electra is a young woman who works in a multinational corporation and she returns at home every day early in the afternoon. She has a specific diet program for every week so the system knows exactly the recipes that she has to prepare each day.

4.2.3.1 Beginner cook scenario

Jim had too much workload today and he was not able to have any meal other than breakfast. The dinner time approaches. Jim does not have a special recipe in mind so he enters the kitchen room and approaches the refrigerator display. The daily schedule is available, as well as the dinner suggestions of the system that he chooses to browse on the kitchen countertop. After his research, he decides to cook the Creamy spinach stuffed mushrooms. He previews the recipe before he starts with the preparation. The recipe is adjusted to the people that will consume the meal. The system provides two servings because of the cohabitation with his sister. Jim decides to add a guest that is about to visit them tonight and the system instantly adopts to this situation and recalculates the portions of the ingredients. Jim now is ready to start the cooking process.

As we mention above, Jim requires specific guidance when he is cooking. He prefers the step by step view of the recipe so the system begins with the first step. The system is aware about his profile and preferences and suggest Jim to begin with the preparation step of the ingredients and utensils before the execution of the recipe. Then he starts preparation process. The preparation process contains the collection of ingredients and utensils throughout the kitchen environment, as well as ingredient weighing if it is required. The counter top, the backsplash and the refrigerator display are available for this process, as well as the pantry and the utensils cupboard of the kitchen. The system guides Jim to collect the ingredients and utensils that are required. AmIChef knows that the mixing bowl is in the utensils cupboard so it informs Jim. A light guides Jim to the proper cupboard. When he completes this action, he places the utensils in the color cycles on the countertop. The system detects the utensils on the counter and waits for the ingredients to be collected. The ingredients collection process follows from the consumables zone where the pantry and the refrigerator are located. Through the refrigerator display the system informs the user that the grated parmesan cheese and the baby spinach leaves are required. From the pantry the recipe step requires the garlic. All the required ingredients and utensils are now on the counter top. Some of the ingredients require scaling and chopping. The system guides the user to weight the ingredients and Jim follows this process because he is not experienced enough to know his preferences in order to change the portions on his own. The garlic requires chopping according to the recipe. In order to perform this action, Jim follows the images of the step presented by the system.

The preparation phase is over and is followed by the next step which is adding the ingredients to the bowl. Grated parmesan is already on the counter and ready from the preparation phase. Jim collects the remaining ingredients. He executes the instructions and moves on the next step.

At this point the system notifies Jim that a future step which requires the oven function is detected and begins the preheating of the oven. The instructions of the next step are available on the kitchen wall but he searches for more information about the final state of the step so he decides to browse the multimedia related to the specific step. First of all, he browses the photos with touch and air gestures through the countertop and then watches the video of the step. In order to control the video, the user uses voice

commands such us star, pause, forward, stop etc. because their hands are busy performing the action simultaneously. He completes the step with this kind of help.

The next step is about chopping the mushrooms and Jim is not familiar with this action, so he decides to use the video about this step. He is watching the whole video but he is still not able to complete the step, so he decides to watch it using the step by step functionality and simultaneously try to complete it. He is finally chopping the mushrooms.

He is now moving to the next production which is to stuff the mushrooms. He has to prepare the oven pan first, which he completes it in an easy manner. After collecting the mushrooms, Jim browses the photos because he is not sure about the process of this cutting method. He makes one step at a time looking at the photos step by step and he succeeds. Afterwards, he arranges them on the pan.

The next step is about filling the mushrooms with the cream cheese from the previous production.

As a last step Jim has to bake the mushrooms. The oven is already preheated and is ready for the mushrooms to be placed inside it. A timer appears for the baking mushrooms. As Jim waits for them to bake, he is able to choose a side dish or a pairing.

4.2.3.2 Advanced cook scenario

It is 19:20 and the system reminds Electra that she needs to begin with the cooking process in order for the dinner to be ready at 21:00. This is usually the time that she and her husband Jonathan have their dinner every night. The dinner for tonight is juicy chicken fillet with carrot puree and sauce Anevato. Electra is an advanced user and she does not prefer to use the preparation process of the system, so she starts right away with the step by step view of the recipe. The system starts with the first production which is the puree. The system at this stage has flexibility with the collection of the ingredients and the utensils and the user can collect them on her own at any time during the cooking process. Electra starts the recipe and the cooking process begins.

The first step is about peeling the carrots and potatoes. The prerequisite for this step is the paring knife for the peeling, and the carrots and the potato as ingredients. The system illuminates grey circles on the kitchen counter about the missing ingredients and utensils of the particular step. The system also guides the user to the right cupboard

where the carrots, potato and the paring knife are located. Electra brings them on the counter and places them on the circles and then the circles illuminates with purple color, meaning that they are in the right location for the execution of the step. She is now ready to execute the step. She knows how to peel the carrots and the potato so she does not use the multimedia of the step.

The second step which is about washing the peeled vegetables. She uses the fruit and vegetable washer for this action. A 2-minute timer starts for the washer.

The third step is about chunking the carrots and potatoes. The vegetables are about to be mushed for the production of puree, so no specific way of chunking is needed. The system suggests Electra to chunk them as small as she can without a specific cutting technique.

The fourth step is about boiling the vegetables. Electra knows that in the boiling action she needs a stock pot, so she brings it on her own and she places it on the counter. The system recognizes it so the circle illuminates with purple color. She needs also water for boiling, signaled by an illuminated grey circle. Electra brings the water. The system detects a future step that requires the hob and asks Electra to confirm or cancel the preheating of the hob at high temperature. She confirms the preheating. The timer about the washer is done and the vegetables are ready for boiling. She adds them inside the stock pot and a stopwatch is set in 20 minutes.

The next steps depend on the completion of the previous step, so the system suggests to Electra to move to a next production in order to utilize the 20 minutes remaining for the boiling. She confirms this suggestion. This step is about grinding the mastic and the cardamom. She brings the ingredients and utensils on the counter and grinds them. Afterwards she places them on the side. All the next steps are depending on the previous undone steps, so she cannot execute another step and she decides to bring some ingredients and utensils in order to be prepared for the next steps. She is browsing the next steps and she needs a drainer, a slicer, a saucepan, the mixer and the tongs. She also needs the chicken, the butter, the milk, the cheese and the wine. In front of cupboards a light illuminates which shows the next ingredients and utensils that are needed for the rest of the recipe and are related to the current step. She brings them and places them on the counter. The stopwatch needs 5 minutes more to end according to

the recipe step, but Electra decides to stop it because according to her experience and preferences the vegetables are ready. The system, right after this action, informs her that it is about to preheat the hob for the next step of making the puree at low heat.

She confirms it and she moves to step six which is to grate the carrots. She uses the grater. She is moving to step seven. Together with the potato and butter, she adds them in a saucepan over low heat, beats them with a mixer and mashes them. Next, she slowly adds the milk and, if necessary, a little of their broth which is in the side. Last, she adds the fresh butter, salt and pepper which are right beside her. The puree is ready and she removes it from the hob.

She is moving to the second production which is the chicken. On the counter, Electra can see that she has one kilogram of chicken and she needs just the half of it. She uses the integrated scale and the 4 chicken breasts are about 600gr. She boils the chicken breasts inside the carrot broth for 4 minutes. She waits for the stopwatch. Then, she strains them. The mastic and cardamom mixture are already done. She pours the aromas into the olive oil which is right beside her, where she browns the fillets. After 2-3 minutes, and after turning the fillets on both sides with the tongs, burns off with 2 cups of wine and boils for another 4 minutes, so a countdown timer starts for 4 minutes. At the end she removes the chicken breasts from the pan, adds the cheese, turns off the heat immediately and mixes gently to melt the cheese well and get the aromas of the pan.

4.3 User Requirements

This section presents the high-level functional requirements that AmIChef and the related displays (i.e. kitchen counter, kitchen wall, refrigerator) need to satisfy. Such requirements have been collected through an extensive literature review and an iterative elicitation process based on multiple collection methods, including brainstorming, focus groups, walkthrough, observation and scenario building.

4.3.1 High Level Requirements of the System

General Functionality

The residents should be able to have an abundance of options in the kitchen environment that support their daily activities which are related with the cooking

process or with their daily schedule and entertainment. Those could be options about media, security, home and notifications, entertainment, garden, manage their inventory, shopping list, weather and cooking.

FR-1: The resident should be able to be supported through the cooking process.

FR-2: The resident should be able to view and edit their daily calendar.

FR-3: The resident should be able to manage their kitchen supplies, edit their shopping list and make online purchases.

FR-4: The resident should be able to view their home notifications. For example, notifications about their daily meetings based on the current time, social media notifications.

FR-5: The resident should be able to view today's news.

FR-6: The resident should be able to view and edit the to do list e.g. daily checklist.

FR-7: The resident should be able to view and edit their blank notes e.g. paintings and free drawings.

FR-8: The resident should be able to view and navigate through their multimedia.

FR-9: The resident should be able to receive an invitation that is time to start the preparation of their meal according to the user preferences or calendar.

Cooking Related Functionality

The resident should be able to access the cooking option and browse through personalized suggestions for cooking recipes, through a variety of cooking recipes or their cooking book, plan a meal, browse their meal history.

FR-10: The resident should be able to browse through personalized suggestions for cooking recipes and choose a cooking recipe to prepare.

FR-11: The resident should be able to browse through a variety of cooking recipes.

- They should be able to browse through basic meal categories (Breakfast, Appetisers, Soups, Salads, Mains, Desserts, Snacks and Favourites).
- They should be able to apply filters (dish type, meal type, time, rating, main ingredient).
- They should be able to search for a recipe by their name

FR-12: The resident should be able to view details of the recipe which are the following:

- Name of the recipe
- Description of the recipe
- Authors of the recipe
- Reviews of the recipe
- Cooking ingredients with their quantity and measurement unit
- Cooking utensils with their quantity
- Cooking devices of the recipe
- Waiting time of the recipe
- Execution time of the recipe
- Baking/ cook time of the recipe
- Total time of the recipe
- Servings
- Difficulty/ Level of the recipe
- Rating of the recipe
- Productions/ Steps of the recipe
- Nutritional Chart of the recipe
- Multimedia of the recipe
- Related Recipes

FR-13: The resident should be able to add a cooking recipe to favorites recipes.

FR-14: The resident should be able to adjust the servings of the cooking recipe.

FR-15: The resident should be able to preview recipe steps.

FR-16: The resident should be able to start a cooking recipe.

FR-17: The resident should be also able to navigate through their cooking book, create their own recipes and save them. They should, also, be able to navigate through their favorite recipes.

FR-18: They should be also able to create meal planning in a daily or weekly base for one or more meals.

FR-19: The resident should be able to browse their cooking history Daily, Weekly or Monthly and reselect a recipe for preparing.

FR-20: The resident should be able to collect the ingredients and utensils around the kitchen environment that are needed for the selected recipe prior or simultaneously with the execution process/ steps of the cooking recipe.

FR-21: The resident should be able to view the required ingredients and utensils of the cooking recipe and details about them.

FR-22: The resident should be able to view the required quantity of the ingredients and utensils.

FR-23: As far as cooking ingredients are concerned, the resident should be able to view the unit of measurement.

FR-24: The resident should be able to scale the ingredients in an effortless and instantaneous way.

FR-25: The resident should be able to adjust the quantities of the ingredients during the preparation of the meal.

FR-26: The resident should be able to be informed if they are running out of an ingredient and add it to the shopping list.

FR-27: The resident can execute a cooking recipe in order to prepare a meal.

FR-28: The system assists the user by showing the steps of the cooking recipe one by one alongside with the utensils and ingredients status.

FR-29: The resident should be able to view the cooking recipe in an overview or in a step-by-step view.

FR-30: The resident should be able to view the order of the recipe steps and navigate through them.

FR-31: The resident should be able to view which steps can start anytime and which cannot due to the necessity of the output of the previous step(s). For example, if a step requires an ingredient which is made in the previous step(s) they cannot execute the step before the execution of the required step(s).

FR-32: The resident should be able to view the progress of the recipe, their current position in the running recipe and the steps that are in progress.

FR-33: The resident should be able to view a cooking step description and author tips about the step.

FR-34: The resident should be able to view the ingredients with their quantity and unit of measurement, the utensils and the devices with their quantity that are required for a step execution according to the cooking recipe.

FR-35: The resident should be able to view the status of the devices. For example, they will be able to see details such as the on/ off mode, the temperature of the device and operating time if there is needed.

FR-36: The resident should be able to view multimedia about the step, play, pause and navigate through them.

FR-37: The resident should be able to receive notification about a timer that starts for a step that requires a specific time to be completed.

FR-38: The resident should be able to receive notifications through the cooking process for a timer that is about to finish and choose if they want to continue the timer or finishing it.

FR-39: The resident should be able to handle the function of the devices related to the cooking recipe.

FR-40: The resident should be able to stop the execution of a cooking recipe.

4.3.2 Interaction design functionality

The following interactions techniques are provided in order to facilitate interaction with the system. AmIChef provides those techniques simultaneously and the user can interact on his preferable way when it is appropriate according to them. For instance, touch gestures may not be appropriate while cooking and voice commands may not be appropriate in a noisy environment (water running or boiling, kitchen aspirator working, etc.). So, the user can swap between interaction techniques when it is required.

FR-41: The resident should be able to interact with the counter and refrigerator displays through touch gesture.

FR-42: The resident should be able to perform simple gestures (e.g. swipe left/right to change the step of the recipe), in order to facilitate interaction with the backsplash display.

FR-43: The resident should be able to use voice commands (e.g. start timer), in order to facilitate interaction with the system.

Chapter 5
The AmIChef Approach

The 'AmIChef' platform is a context-sensitive cooking system that supports the residents of an intelligent home and provides interactive, multimodal, intuitive, and user-friendly assistance while preparing a meal . In particular, it aims to transform the kitchen environment of an Intelligent Home into an interactive place that can host cooking applications and display appropriate multimedia content towards supporting residents while preparing a meal of their choice. The resident has the ability to interact with the installed technological equipment, which consists mainly of large interactive displays and smart appliances (which are interconnected with the kitchen environment), browse and execute recipes, manage kitchen supplies, plan their meals and have access to the meal history.

The basic functionality of the system consists of browsing individual suggestions for cooking recipes with the ability to customize them according to their preferences, as well as the ability to execute these recipes with real-time feedback on steps, ingredients, cookware, as well as the time and actions they need to manage and implement in order to reach the desired result of the recipe. Residents have the ability to view the steps of the recipe in combination with the ingredients and cooking utensils that need to be collected from the surrounding kitchen environment step-by-step, as well as the actions they need to take during the process of performing the cooking steps. The goal is to make the culinary process as easy, safe, quick and efficient as possible. Towards that direction, AmIChef will serve through all the basic cooking zones in the kitchen environment (Section 2.1): (A) Consumables Zone (B) Non-Consumables Zone (C) Cleaning Zone (D) Preparation Zone (E) Cooking Zone.

5.1 Challenges

During the design process various challenges were faced and the design team had to identify sophisticated mechanisms that permit residents to view and interact with the available user interfaces in an easy manner, given the affordances of Distributed User

Interfaces (DUIs) [49], [74],[75] which apply the notion of distributing parts or whole of a user interface (UI) across several places or locations. The most intriguing challenges that the design team faced are:

Challenge A. Considering the fact that residents' hands may be occupied/dirty anytime during the cooking process, what would the most efficient interaction modalities be?

Challenge B. What alterations/disturbances can be made to the cooking process so that AmIChef is not considered intrusive?

Challenge C. How often should AmIChef ask for the user's attention?

Challenge D. On which artifact each piece of information should be displayed?

5.2 The Intelligent Kitchen

Inside the Intelligent Kitchen environment, everyday user activities are enhanced with the use of innovative interaction techniques, artificial intelligence, ambient applications, sophisticated middleware, monitoring and decision-making mechanisms, and distributed micro-services. Regarding the programmable hardware facilities of the "Intelligent Kitchen", they currently include (or it is planned to include) both commercial equipment and technologically augmented custom-made artifacts.

Common domestic equipment include a wide variety of commercial devices (e.g., Philips Hue Lights, blinds, Alexa, and appliances (coffee machine, air-conditioner) that can be controlled either via their own API or by using dedicated solutions. Additionally, technologically augmented objects of the kitchen include (Figure 22):

- **Refrigerator** *[Consumables Zone]*. A refrigerator with an embedded large display can present situated information regarding the required ingredients that a resident has to get from the refrigerator according to a specific recipe step.
- **Smart Pantry** *[Consumables Zone]*. The pantry is a special cabinet in a kitchen environment where beverages, food and other long-lasting food ingredients are stored. The pantry of the Intelligent Kitchen is equipped with technologically enhanced shelves and smart containers so as to provide intelligence regarding the ingredients that the user manipulates at any given time.
- **AmICountertop** *[Preparation Zone]*. This is a regular work surface able to transforms into an interactive display. Sophisticated mechanisms permit the

countertop to be aware of the number and type of items (i.e. ingredients, utensils). Object detection mechanism in combination with the technology of the multitouch display above the countertop permit this functionality. This information is available through services in the context of the intelligent home.

- **AmIBacksplash** *[Preparation Zone]* This is a system adjacent to the countertop that can be used either as a primary or secondary display.
- **Smart Scale** *[Preparation Zone]*. The AmICountertop can double as a digital kitchen scale, by adding load sensors. A Smart Scale permits the system to know whether the user has utilized the correct quantity of several ingredients.
- **Cookware Inventory** *[Preparation Zone]*. It refers to a special cabinet that includes the cooking utensils and objects that a user requires to perform cooking actions. In the Intelligent Kitchen this cabinet is located around the countertop in order to be easy for the user to access the required tools. Similarly, to the Smart Pantry, it is also equipped with technologically enhanced shelves and smart containers.
- **Cooktop** *[Cooking Zone]*. Cooktop is an electronic device, also known as hob, commonly used for cookery to apply heat to the base of pans or pots. Cooktops are often found integrated with an oven into a kitchen stove but may also be standalone devices. The Cooktop of the Intelligent Kitchen is standalone and comes equipped with Wi-Fi, allowing AmIChef to monitor and control it whenever needed.
- **Oven** *[Cooking Zone]*. The oven of the Intelligent Kitchen is Wi-Fi enabled, and delivers some extra functionalities, such as precise temperature control, automatic preheat, automatic turn on/off, electronic timer, etc.

Finally, the software infrastructure of the intelligent kitchen offer access to various information:

Resident Demographics. It provides information about each resident such as their age and height. AmIChef can use this information to adjust the recipe portions appropriately to accommodate all the residents of the home.

Resident Profile. It includes information regarding the residents' cooking experience. It can be used to personalize the type and amount of assistance that should be provided. Such information could be the cooking level of the user, for instance beginner or

advanced. These are related to the information of that the system provide. The beginner cook receives a step by step assistance although the advanced cook is starting a recipe with an overview mode of the recipe. Additionally, it contains information regarding the **nutrition preferences** of the residents (e.g. meals that they do not prefer, or ingredients that they do not want to include in their nutrition). The latter when combined with **health**-related information (e.g. allergies) can help AmIChef identify whether there are restrictions on the diet of individuals, so as to exclude recipes with specific ingredients or propose appropriate replacements when making suggestions.

Calendar. It contains the scheduled events of the residents. Having access to a resident's calendar could help AmIChef to suggest an appropriate recipe depending on the available time for preparation/cooking.

Kitchen Inventory. It is aware of the kitchen supplies, as well as of the cooking utensils that are available in the home and their location inside the kitchen.

Figure 22: A 3D representation of the Intelligent Kitchen of ICS-FORTH

5.3 Interaction Paradigm

One of the main characteristics of AmIChef is the incorporation of multiple input/output channels that enable interaction even when a user's primary channel is occupied, unavailable, or non-existent. In more detail, the following input modalities are provided:

Virtual pointer. Users can control the interfaces by hovering their hand over the Leap Motion sensors, which are embedded in key locations inside the kitchen. A virtual cursor that follows the movements of their hands enables them to focus on and select areas of interest.

Mid-air gestures. Appropriate mid-air gestures, such as palm tilt, finger pinch, and hand swipe are also available in order to permit users to complete specific actions (e.g next/previous item in a list, zoom in/out) quickly and in a natural manner.

Touch. AmICountertop, AmIBacksplash and the Refrigerator feature touch-enabled surfaces, which, depending on the context of use, are able to display various interactive touch-enabled controls (e.g. move to next or previous item on a list, stop a timer).

User presence and position. Motion sensors mounted on various locations in the kitchen permit the detection of user presence inside the room. Knowing when one or more users are inside the room is quite important for deciding when to present specific information (e.g. when the user is near the refrigerator, its display presents the ingredients that must be collected).

Object detection. When a physical object is placed on top of AmICountertop, its presence can be identified via external third-party sophisticated software. This software can identify the type of the object, and it can estimate the space it occupies. The ingredients are placed into smart containers that approximately calculate their position, size and amount. The kitchen selves integrate technology that recognizes the items they contain along with their position.

Voice commands. Simple voice commands are supported (e.g. start timer), while the users can also record short phrases as vocal messages.

5.4 AmIChef Functionality

AmIChef aims to be as less intrusive as possible. The goal is not to enforce unnecessary tasks to the residents of the home, on the contrary it is to streamline the cooking process so that even inexperienced cooks can follow complex recipes. So, addressing challenges B and C, AmIChef features two modes, namely: **step-by-step recipe execution**, and **recipe overview**. The first mode permit users to focus on a single step at a time, and get detailed instructions regarding the activities that should be performed, which makes

it appropriate for users that need real-time guidance. In certain cases, AmIChef is aware when the user has completed a step (e.g. the system knows when the oven has finished cooking) and moves to the next one automatically. Nonetheless, the user can navigate to the available steps on his/her own. The recipe overview mode provides appropriate interfaces that are distributed in the available displays in a sophisticated manner, offering an overview of the recipe steps along with the required ingredients and utensils.

The main difference of the two modes is that the first asks the user to perform certain actions in a specific order, while the second mode lets the cook to act more freely. In both cases, AmIChef is aware of the completed tasks and updates the displayed information accordingly. For example, in the recipe overview mode, when the system identifies that the cook has retrieved from the refrigerator specific items, the UI representing the ingredient list is updated with appropriate indications for the retrieved items. Additionally, the guidance that AmIChef offers is always present, but in the overview mode the cues provide are subtle and less intrusive. The resident is not obligated to use the exact quantities concerning the ingredients, although the system informs them about a possible failure in case a threshold in the quantities is exceeded, which mean too much of an ingredient or too little.

The complete functionality of AmIChef is described below:

Browsing Recipes

The resident has the ability to browse through a variety of categorized cooking recipes. They have the ability to browse through basic meal categories (Breakfast, Appetizers, Soups, Salads, Mains, Desserts, Snacks and Favorites). Additionally, they have the ability, to search for a recipe and apply filters such us dish type, meal type, time, main ingredient, pantry ready recipes or favorites in order to find a recipe of their preference. Residents can view recipes with their details, ingredients, cooking utensils and nutrition facts, as well as add them as favorites, add them to the meal plan, add the recipe ingredients to the shopping list or just preview their steps.

AmIChef can suggest recipes depending on a plethora of parameters based on the profile of the user, as well as the kitchen inventory, calendar and health services. More precisely, the system can access the age, gender, weight, height, medical history, and

preferences of the resident, as well as stock information about cooking ingredients and utensils in order to find the appropriate suggestion for the user.

When the user wants to start the execution of a recipe, they can configure it (e.g. change the servings so that the system can automatically change the portions of ingredients).

Following a Recipe

When following a recipe, AmIChef is either in step-by-step recipe execution mode or in the recipe overview mode. In both modes, the users can perform the tasks mentioned below, either by following specific instructions by the system or at their own time of preference.

- **View Recipe state**. Throughout the cooking process AmIChef offers users an overview of the recipe state (e.g. recipe progress, current step, preview next steps).
- **Collect ingredients and utensils**. In the step-by-step execution mode, the system contains steps that specifically ask the users to collect the necessary items before processing them. The system identifies the ingredients and utensils that the user brings on the countertop.
- **Process the ingredients**. In the step-by-step execution mode, in case the ingredients require some kind of preparation (e.g. weighting or chopping), AmIChef provides appropriate guidance that the users can follow in order to complete such tasks.
- **View Multimedia.** Residents are able to access and navigate to the multimedia (e.g. images, video) of a step at any time of the cooking process.
- **Control Kitchen Appliances.** Residents are able to manage the kitchen appliances such us oven and cooktop. The system is able to preheat such appliances automatically when it is appropriate according to the steps, although the user can modify such actions.
- **Use Kitchen Utilities.** Depending on the step, an embedded **scale** can automatically appear on top of the counter so as to permit the users to weight the ingredients. The users can hide the scale from the interface if they do no need to use it. Additionally, in case the recipe step requires the user to set a

timer, the system displays a digital timer that starts automatically. The user can modify or stop the timer manually.

Notifications. Residents receive notifications during the cooking process, which are divided in two categories: (i) **Informative**, i.e. events that require no immediate user actions (e.g. device status or background events, e.g. recipe adjustment or the oven is preheated); (ii) **Critical**, i.e. events that require immediate user actions (e.g. a timer has finished).

Access to the inventory

In order to prepare a meal, a resident should plan getting basic supplies such us cooking ingredients and utensils. They have to ensure that all those required supplies will be available by the time of the cooking process. Our system is able to communicate with the kitchen inventory. With this knowledge, the system can manage to notify resident accordingly when for instance an ingredient is low or out of stock in a desired recipe, and provide the option to add them to the shopping list in order to restock them.

Meal Planning

Meal Planning refers to the ability of the resident to plan their meal on a daily or weekly basis. They can arrange their meals on the day or week according to their willing or certain personalized needs such as medical prescriptions or special diets that they are following. Meal Planning uses the recipe browsing functionality in order to help users to create their meal plan. The system can notify the resident on time about their meal preparation and managing the inventory for the required ingredients according to the meal plan.

Detailed Cooking History

Resident could recall and search by date their cooking history anytime. They could just browse the history's recipes, use them again instantly or add them to a meal plan for future use.

Access to Home Utilities

Residents should have the ability to perform from their kitchen various tasks that support their daily activities, which are either related with the cooking process or with their daily schedule, socialization, or entertainment. Indicative examples of such tasks are: access and manage their home security, receive home notifications, listen to music,

browse their shopping list, check the house inventory, be informed regarding the weather, cook, etc.

Chapter 6
Design & Implementation

6.1 User Interface

The user interfaces of AmIChef are distributed among the basic displays of the system which are the AmIBacksplash, AmICountertop and refrigerator display. The basic functionalities of the system are depicted below as they are represented through user interfaces. (Figure 23) represents the displays integrated in the kitchen at the three locations mentioned above. These images are attached on the user interface images in this Chapter in order to indicate the location in the kitchen where they are displayed.

Figure 23: a. Kitchen countertop, b. Kitchen backsplash, c. Refrigerator

Browsing Recipes

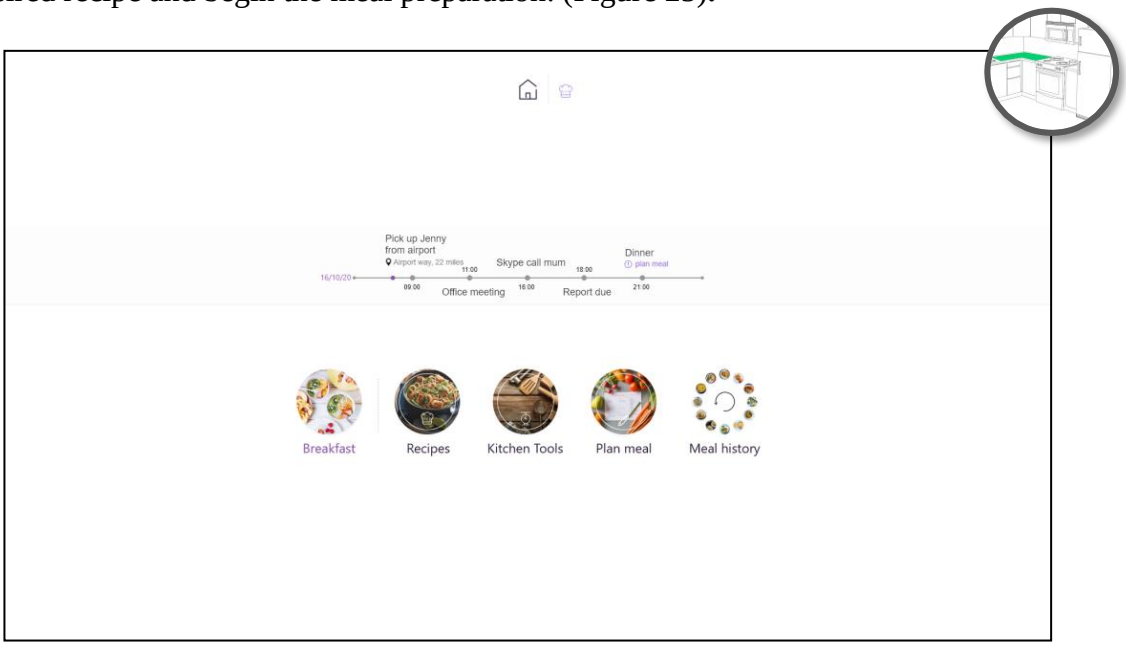
Browsing recipes functionality is provided through the three basic displays as they compose the main workstation of the kitchen environment. Resident can choose either the refrigerator or the AmIBacksplash and AmICountertop to complete this action.

- Residents are able to browse through recipes and view meal categories (Breakfast, Appetizers, Soups, Salads, Mains, Desserts, Snacks and Favorites). They are able to search for a recipe by name in order to find one of their preference (Figure 24).

- The system recognizes that it is time for lunch and the resident approaches the kitchen environment and more precisely the preparation zone which includes the countertop and backsplash display. AmIChef provides personalized suggestions, which are more

likely to be the choice of the resident. They can browse through them, choose the desired recipe and begin the meal preparation. (Figure 25).

a.



b.

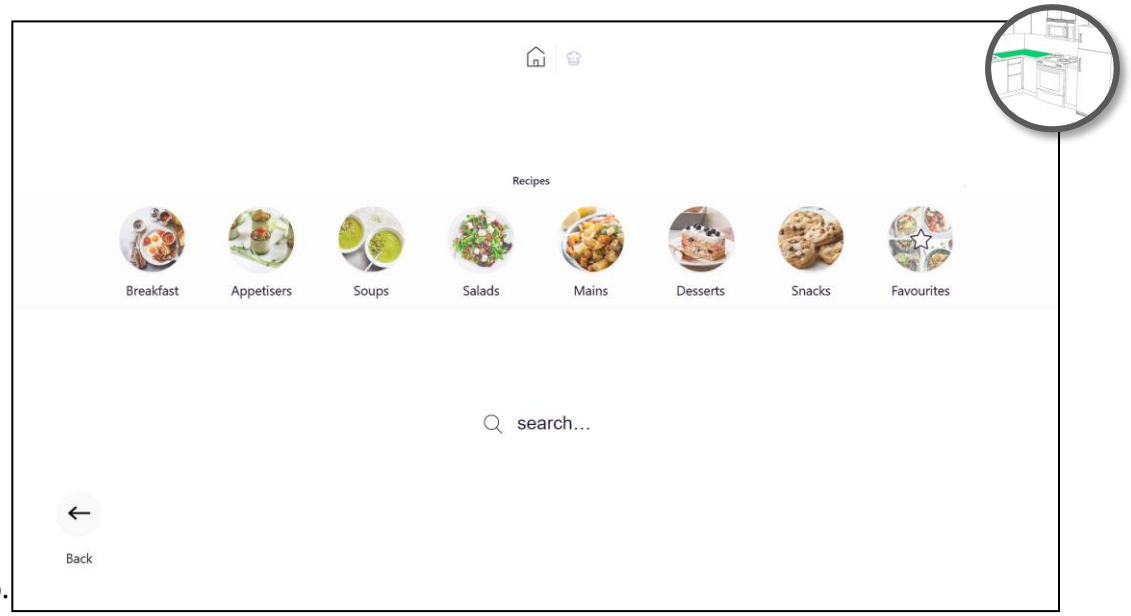


Figure 24: AmICountertop recipe browsing and search

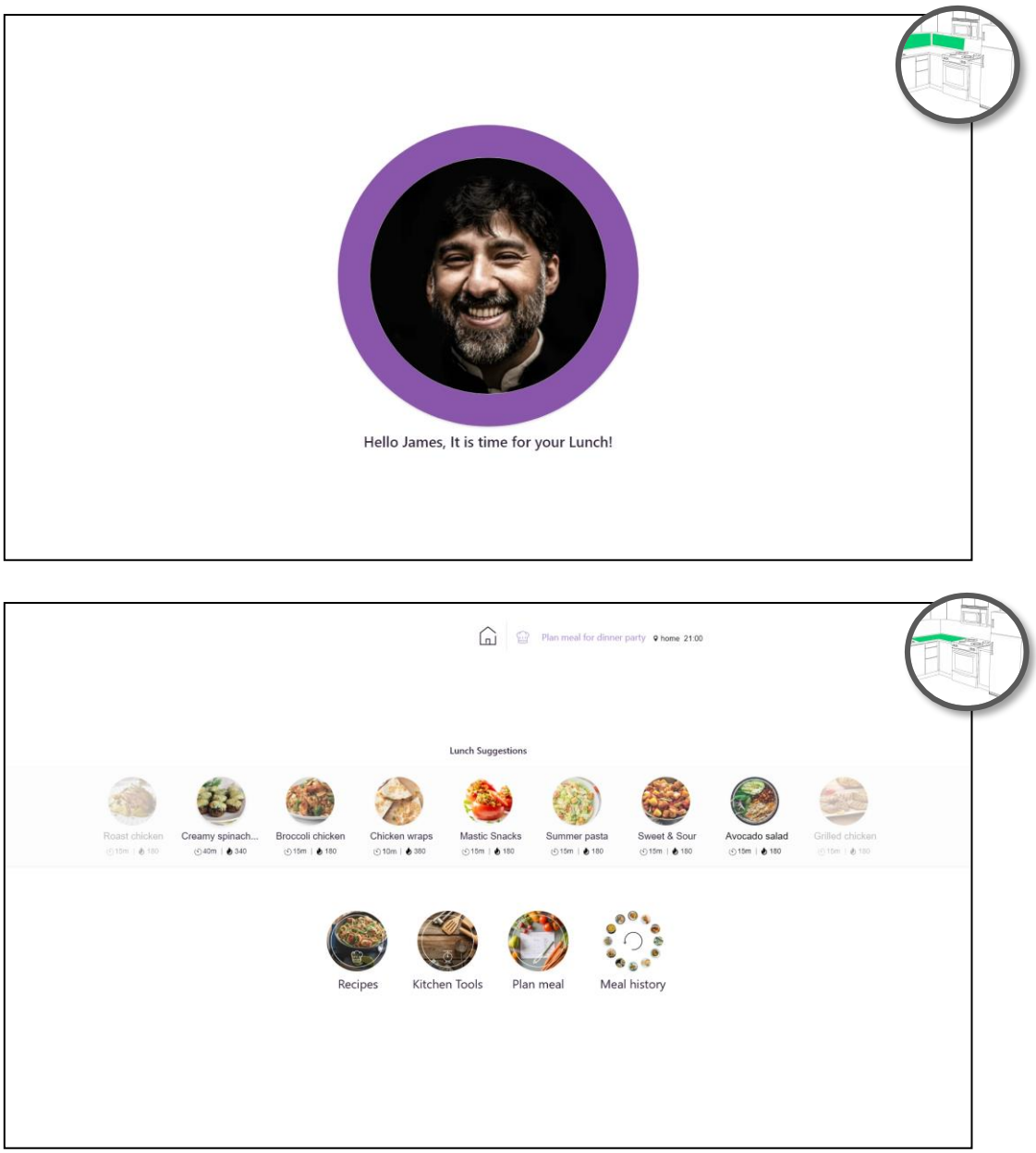


Figure 25: Personalized Meal Suggestions in AmIBacksplash & AmICountertop displays

- The user has the ability to select and browse the details of recipes using the backsplash and countertop displays showing the required instructions, ingredients, cooking utensils and devices with the related quantity. Moreover, they are able to view the required time, the level of difficulty, the productions and nutrition facts of the recipe, as well as add them as favorites, add them to meal plan, add the ingredients of the recipe in the shopping list or just preview their steps. They could make configurations in the recipe such as change the servings. The system automatically recalculates the portions of

ingredients. They could, also, immediately start a cooking process execution of each recipe. (Figure 26)

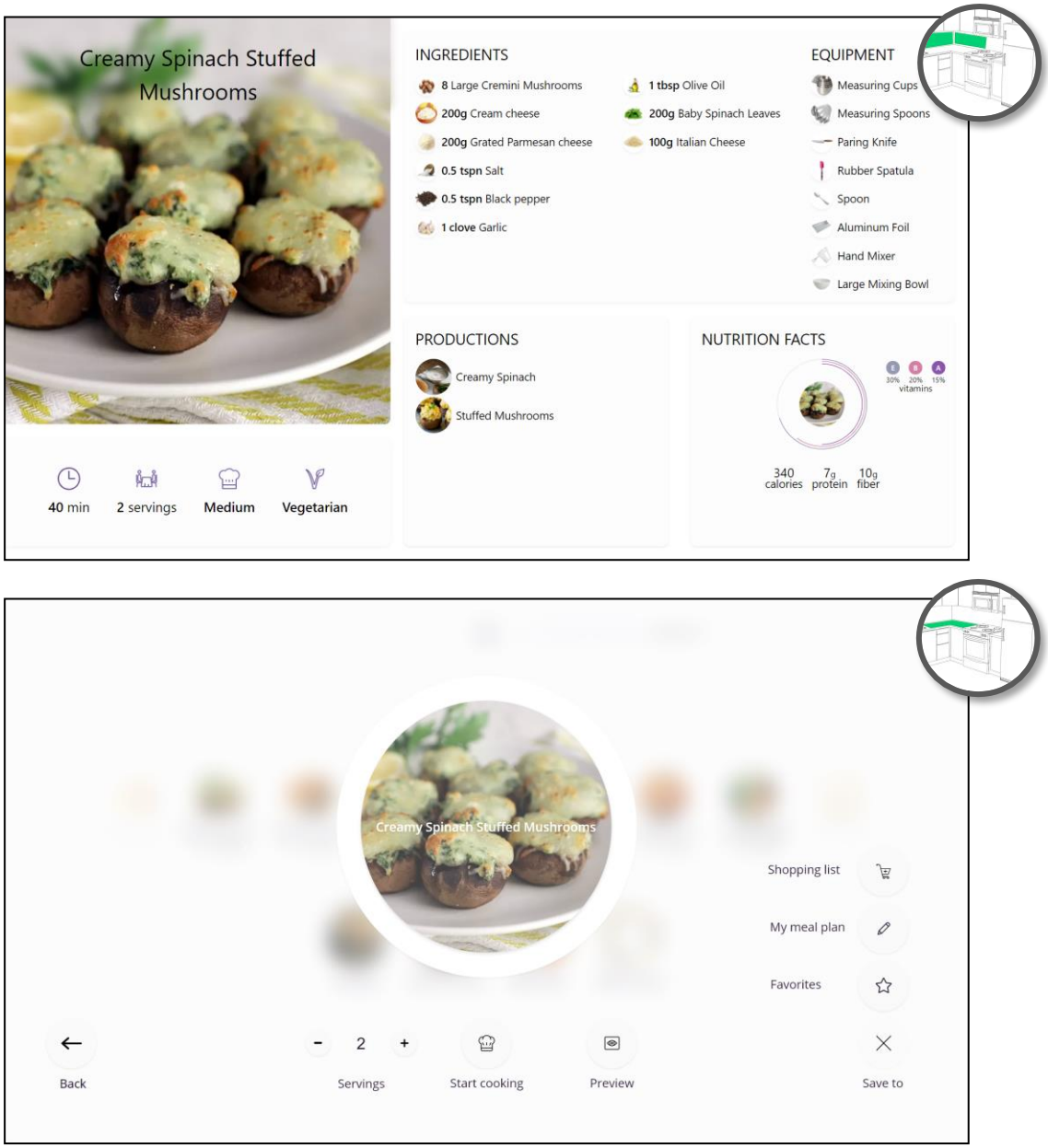


Figure 26: View recipe details and options in AmIBacksplash & AmICountertop displays

Following a Recipe

After the selection and the arrangement of a recipe, the user is able to start the meal preparation. The kitchen environment is aware about that action and adapts to this situation. All the related components operate simultaneously in order to support the meal preparation. The Kitchen backsplash provides the cooking steps of the recipe with

the related cooking ingredients, cooking utensils and devices. When following a recipe in the step-by-step recipe execution mode the users can perform the tasks mentioned below, by following specific instructions of the system or at their own time of preference.

- **Recipe state**. Resident provided with the recipe state (e.g. recipe progress, current step, preview next steps) and is displayed through the AmIBacksplash, AmICountertop and Refrigerator displays. In the overview mode the recipe productions are available along with their steps. The current step with the required ingredients and utensils is highlighted. The countertop is waiting for the ingredients and utensils (Figure 27). In the step-by-step view through the backsplash a progress bar is available showing the state of the recipe which means the current production and step, as well as the order of the next steps. An image of the final outcome of the step is available, along with the step instructions, the location and required quantity of ingredients, utensils and devices. A control panel presented on the countertop allows the user to navigate across and preview next steps, access and navigate across the multimedia (images, video) or set a new timer and configure it afterwards (Figure 28).

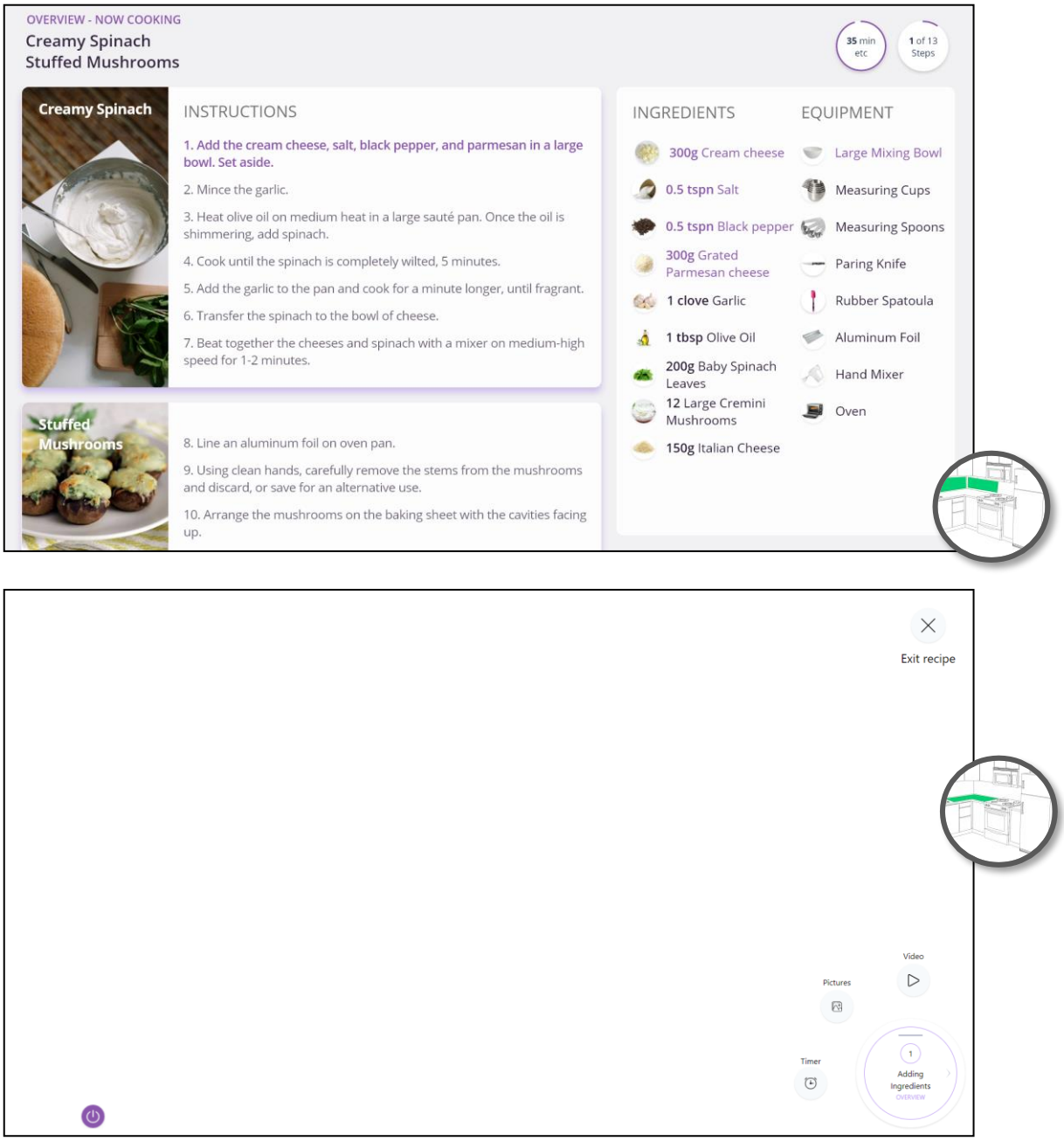


Figure 27: Overview of a recipe at AmIBacksplash & AmICountertop

- **Collect ingredients and utensils**. The whole kitchen environment participates for the completion of this function. More precisely, the directions are given towards the basic displays for the collection of the necessary objects through the consumables and non-consumables zones. In the step-by-step execution mode, the system contains steps that specifically requests the users to collect the necessary items before processing them. On the countertop, placeholders

appear as circles, showing the required items, their location in the kitchen environment along with the required quantity for each step (Figure 28). Simultaneously, the refrigerator displays the ingredients that are required for the current step in order to facilitate the process and display the required objects on the visual field of the residents when they attempt to collect them (Figure 29).

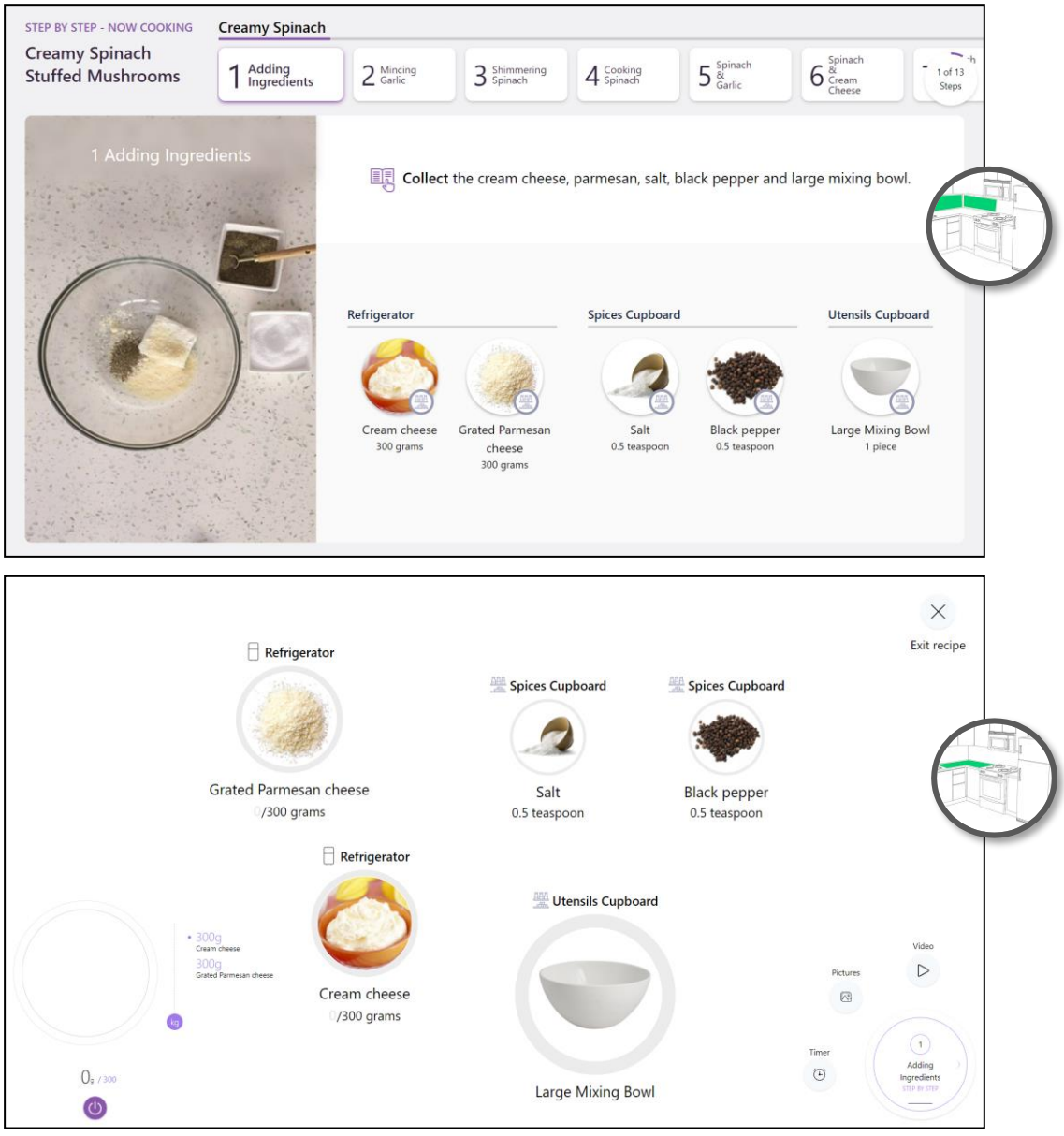


Figure 28: Collection instruction step-by-step mode in AmIBacksplash & AmICountertop displays

Figure 29: Refrigerator during collection step

- **Process the ingredients**. In the step-by-step execution mode, in case the ingredients require some kind of preparation (e.g. weighting or chopping), AmIChef provides appropriate guidance that the users can follow in order to complete such tasks. This function is usually completed on the countertop. The AmICountertop is informed about the state of the recipe and guides with illuminated circles the resident. In every step it illuminates the required cooking ingredients and utensils and informs the user about their location in the kitchen environment. Depending on the step, if scaling is required , the digital scale automatically shows on top of counter and guides the user to scale the right items. The resident uses the countertop as a tangible user interface, as well as a touch surface in order to perform their actions. As they bring the required items, they can place them on the circle holders and the progress bar which is integrated illuminates with colors depending on the quantity of the ingredient. It contains four coloring stages, the first one is without the item on the counter, the second one if the quantity of the placed item is below the required, the third

one if it is exactly the required quantity and the fourth, is when the quantity of the placed item exceeds the required quantity (Figure 30). Simultaneously, the refrigerator displays the information about the required quantity of ingredients in order to facilitate the process and display the required objects on the visual field of the residents when they attempt to collect them (Figure 31).

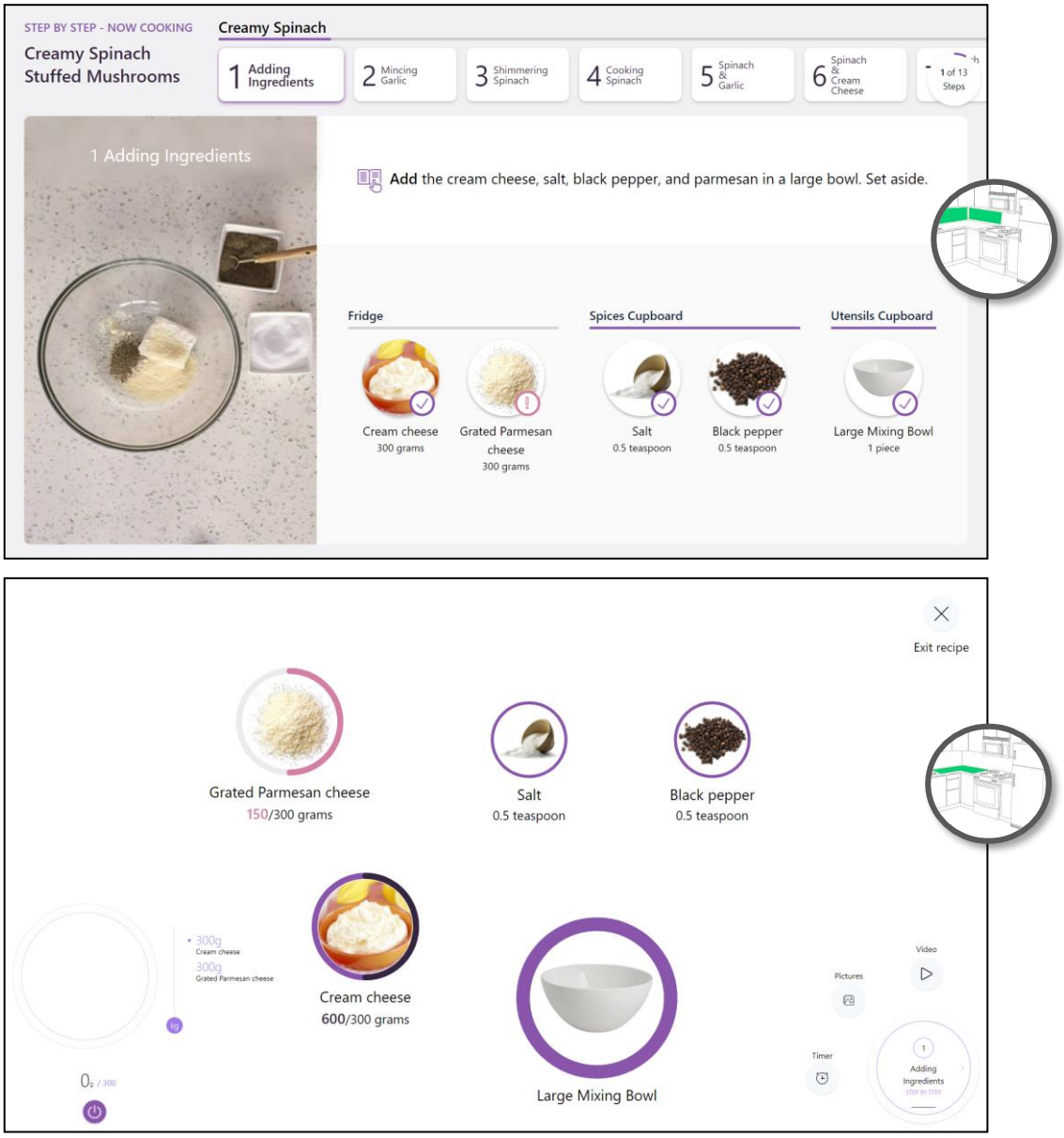


Figure 30: AmIBacksplash and AmICountertop through step 1 collection phase.

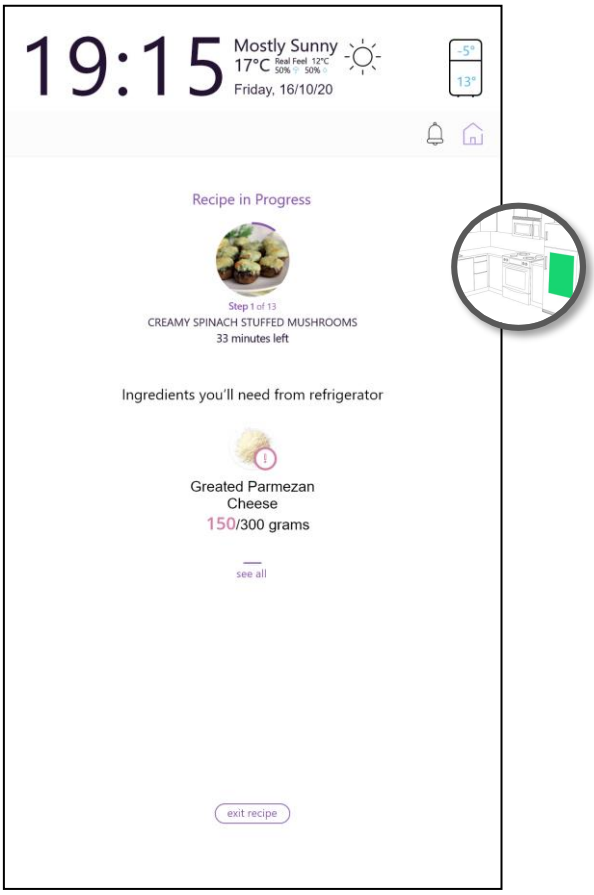


Figure 31: Refrigerator during step 1.

Use Kitchen Utilities. Depending on the step, an embedded digital scale can automatically appear on top of the counter so as to permit the users to weight the ingredients. The users can hide the scale from the interface if they do no need it. Users are not obligated to use the exact quantity of the cooking ingredient that is required from the recipe, but they modify the quantity to a point that it is not prohibitive for the continuity and completion of the recipe (Figure 32). Additionally, in case the recipe step requires the user to set a timer, the system displays a digital timer that starts automatically, nonetheless the user can modify or stop the timer manually with multiple modalities such us touch, mid-air gestures and voice commands (Figure 33).

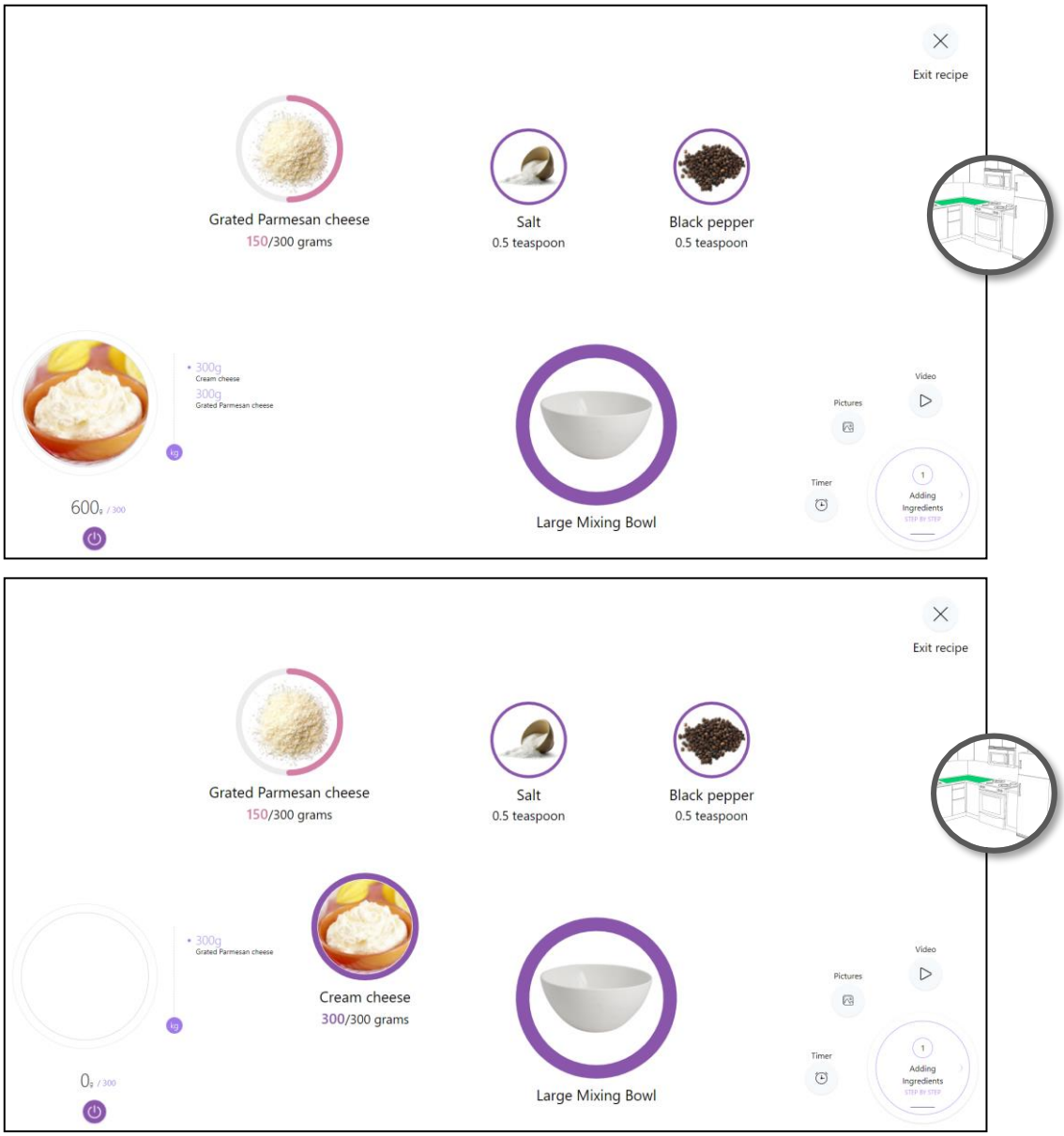


Figure 32: Scaling of the Cream cheese on the AmICountertop

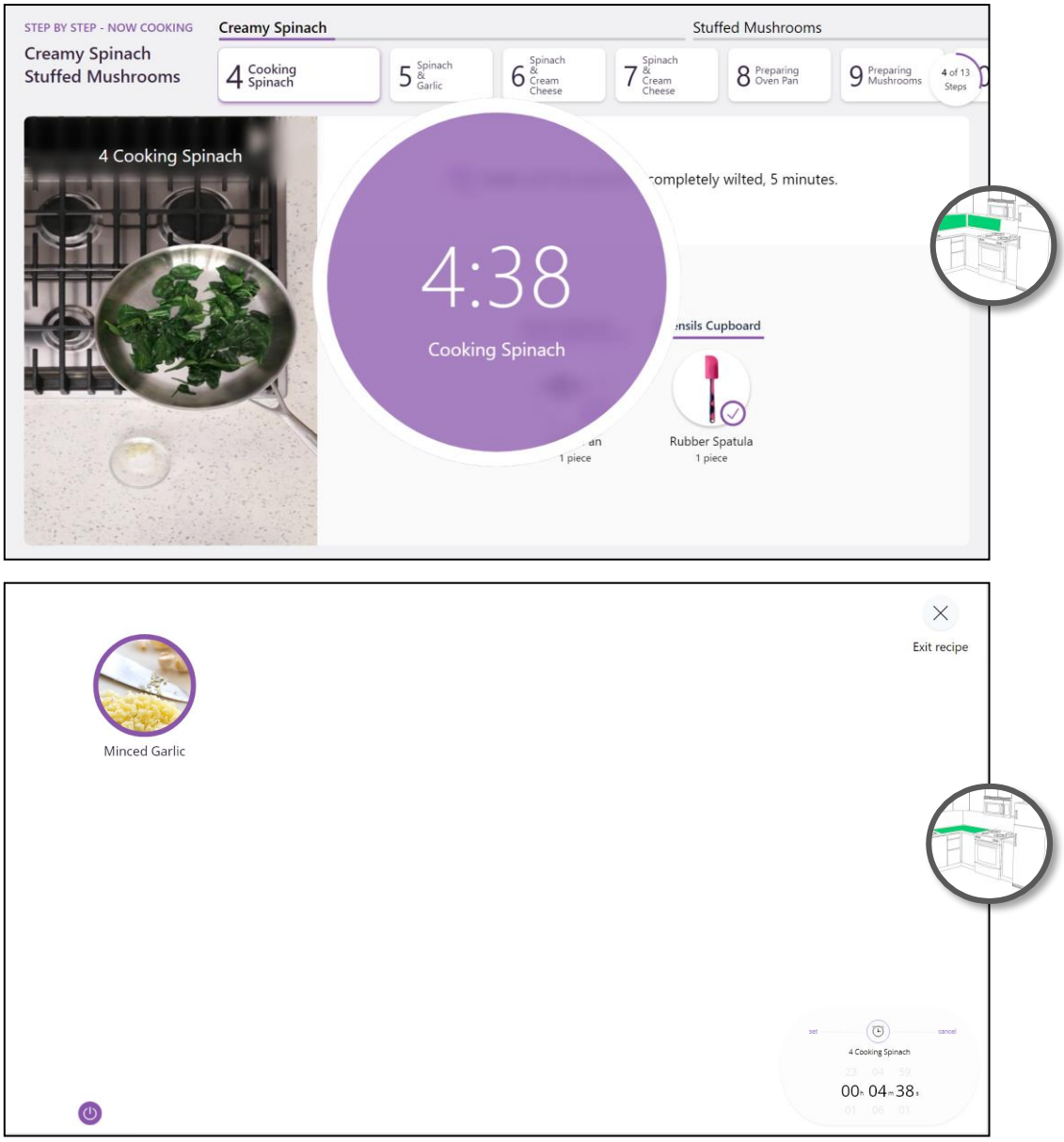


Figure 33: Digital timer on the AmIBacksplash and timer controls on AmICountertop

- **View Multimedia.** Residents are able to access and navigate the multimedia (e.g. images, video) of a step at any time during the cooking process. This functionality is available through the controller menu of the countertop, as well as through voice commands and mid-air gestures. Multimedia can be step instruction images (Figure 34) which show the exact action of a recipe step, and pre-recorded video which shows the whole step performed by a chef. Multimedia are displayed through the AmIBacksplash in order to be available on the user field of view when they execute the recipe steps and be able to control them simultaneously. (Figure 35).

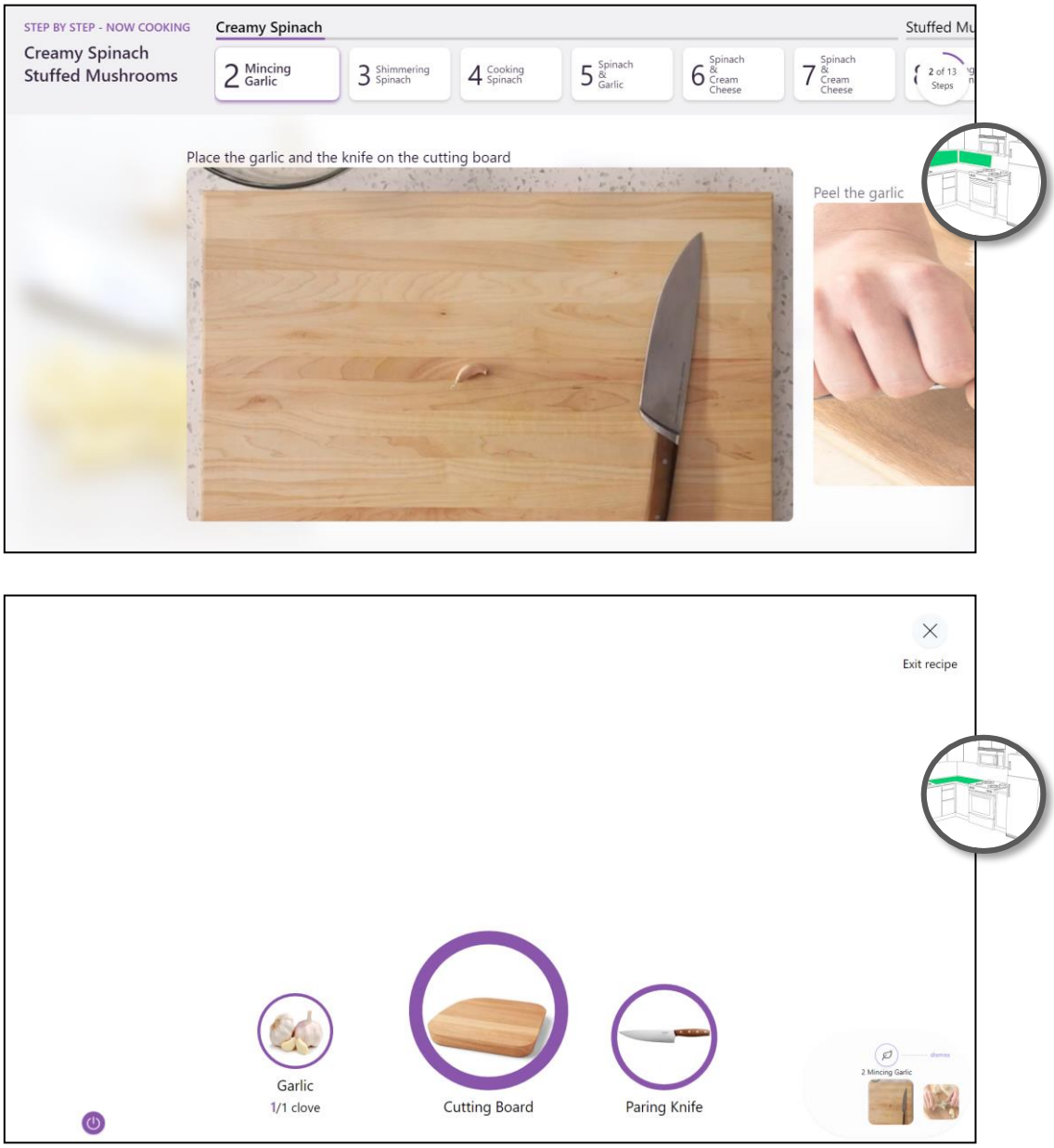


Figure 34: The images of the step at AmIBacksplash and options to navigate through images on the AmICountertop.

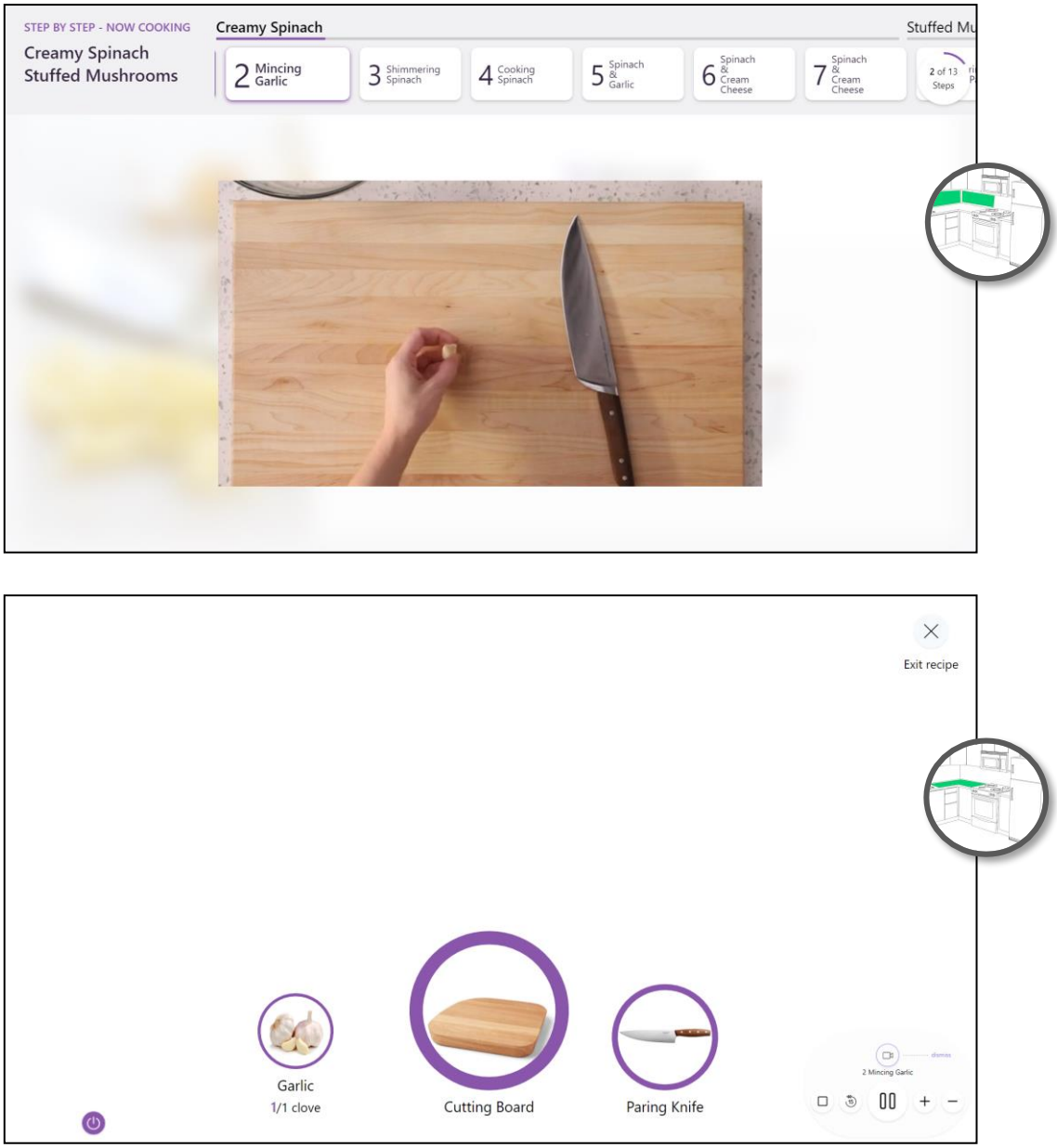


Figure 35: The video of the step at AmIBacksplash and options to navigate through the AmICountertop.

- **Notifications.** Residents receive visual and sound notifications during the cooking process. The notification functionality is available through the three basic displays accordingly to be available in the field of view of the resident at each time. The notifications are divided in two categories. Informative notifications concern events that require no immediate user actions (e.g. device status or background events, e.g. recipe adjustment or the oven is preheated (Figure 36). Critical notifications concern events that requires immediate user actions (e.g. a timer has finish). The system requires a response from the user

which is critical for the progress of the recipe or a safety issue (e.g. a timer has finished for a baking action on the oven). The system notifies the user and requires an action from the user, either to confirm the shutting down of the oven or extend the timer. Otherwise, if the system does not receive a response within two minutes, it shuts down automatically the oven (Figure 37).

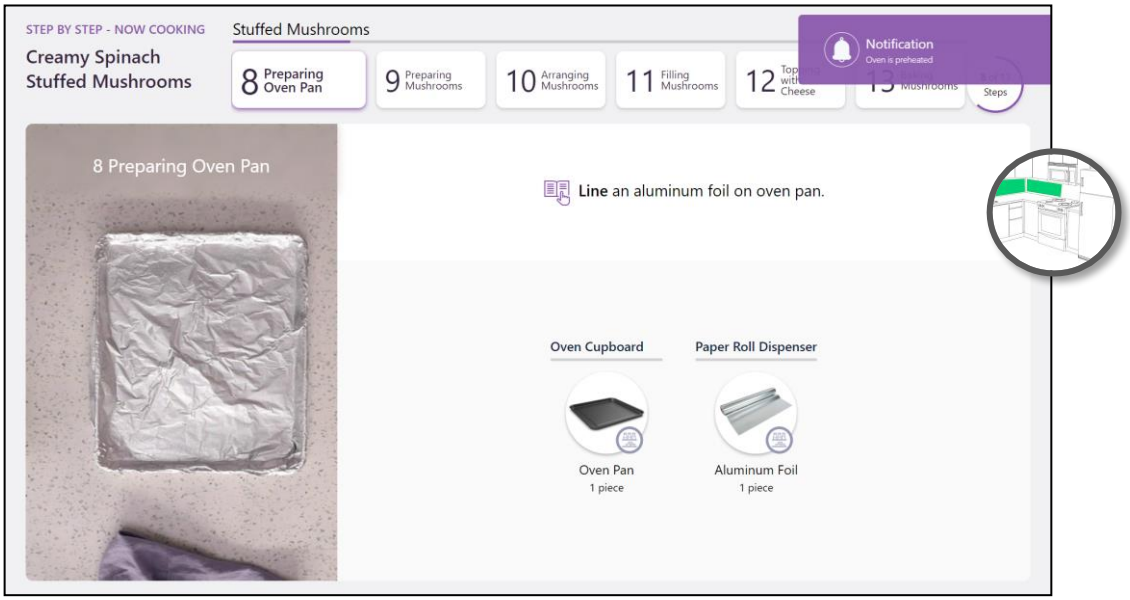


Figure 36: Informative notification. Requires not immediate actions from user.

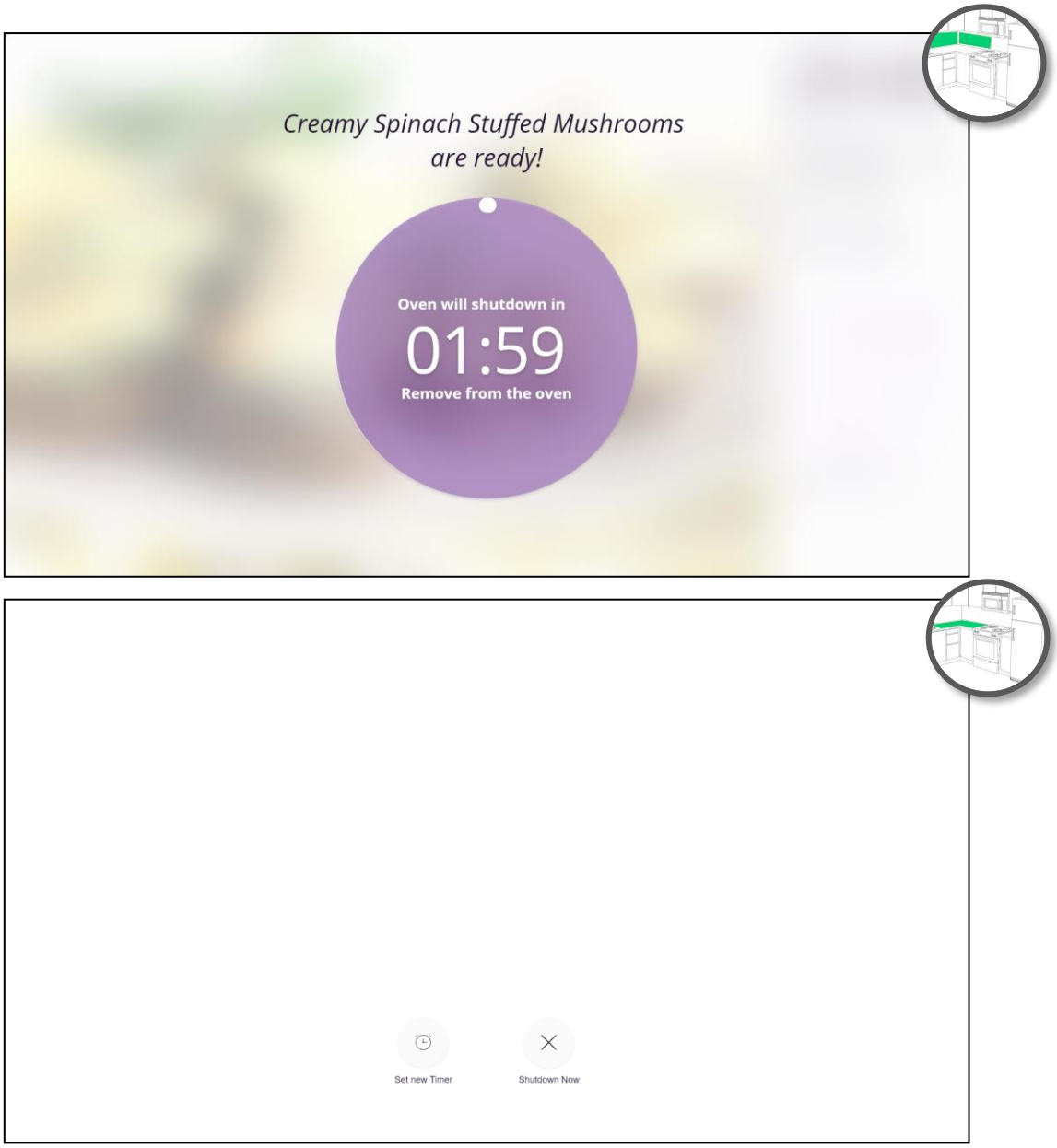


Figure 37: Critical timer, asks immediate user actions

Meal Planning

The meal planning option allows the resident to plan their meal on a daily or weekly basis. They can arrange their meals on the same day or browse through the weeks and add their breakfast, lunch, dinner or other meals during the day. The meal planner uses the recipe browsing functionality in order to help the residents to create their meal plan. Meal planning option is available through the AmICountertop, as well as, the refrigerator and the residents are able to choose where they will complete this action (Figure 38).

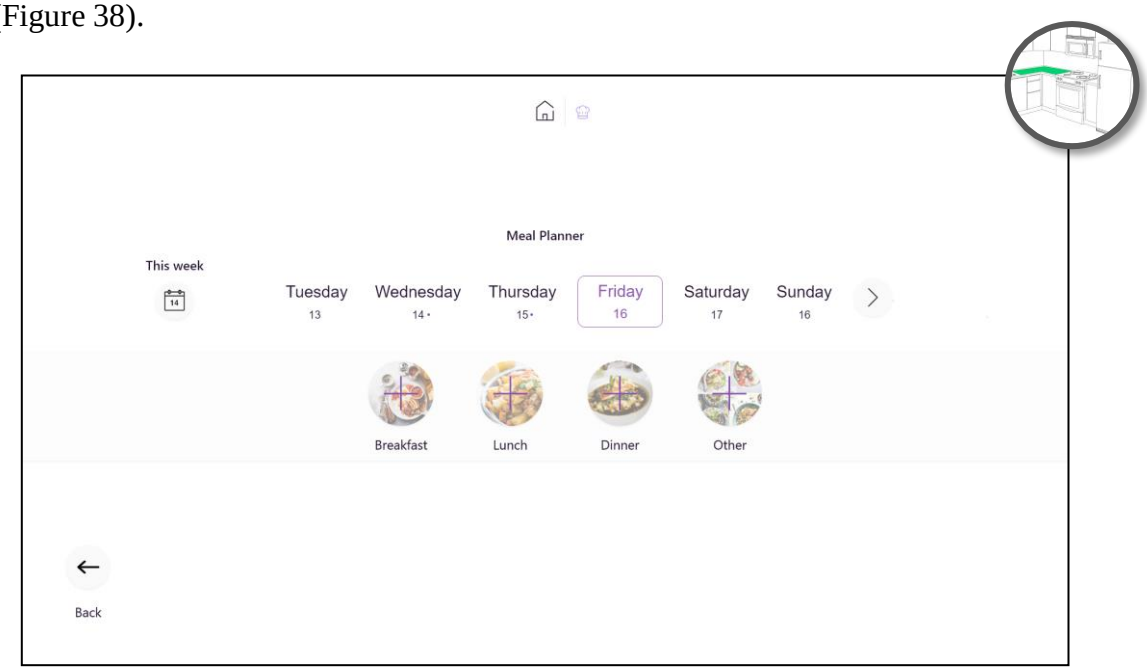


Figure 38: Plan meal page on the AmICountertop

Meal History

The residents can recall and browse by date their cooking history. They can just browse through their meals of a day (breakfast, lunch, dinner or other kind of meals), use them again instantly to prepare their meal, or add them to the meal plan for future meal preparation. Meal history option is available through the AmICountertop, as well as, the refrigerator and the residents are able to choose where they will complete this action (Figure 39).

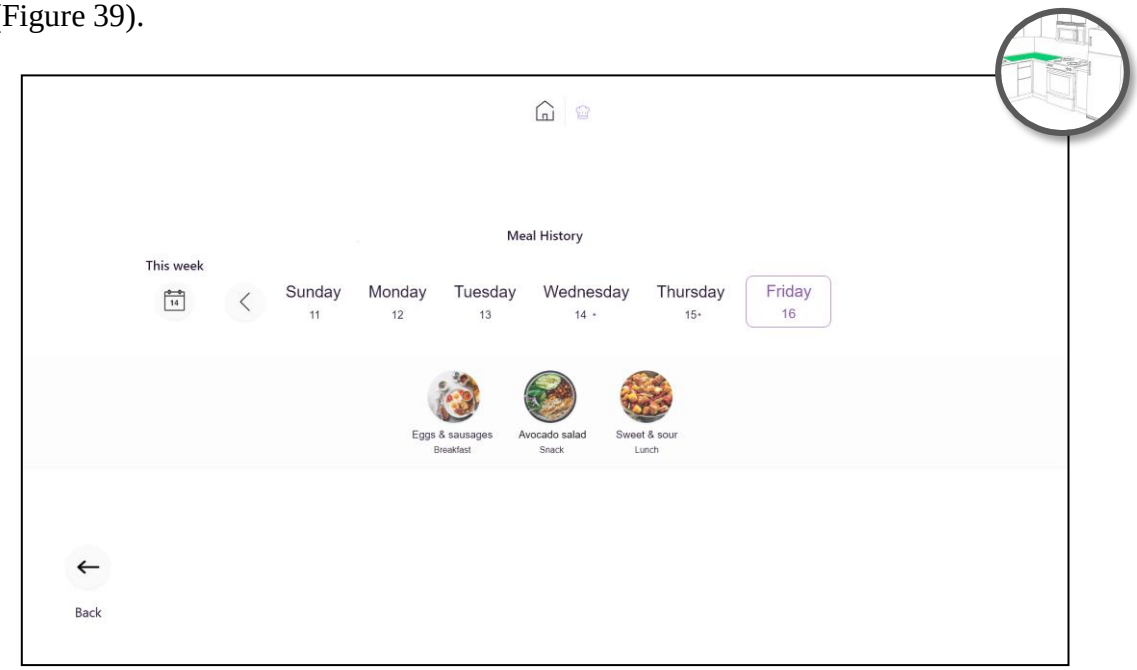


Figure 39: Meal history page on the AmICountertop

Access to various Home Utilities

In order to meet the requirements of a kitchen environment and the tendency to multitasking during cooking process, AmIChef provides options for home management. To that end, it includes a home menu which contains several home options. The home menu could be accessed through the AmICountertop, as well as, through the refrigerator. Those options include access and management of home security, home notifications, entertainment, garden, inventory, shopping list, weather options and cooking related options. This menu can be accessed from the fridge and countertop displays. More

precisely, from the refrigerator home screen the resident has direct access and is able to view the daily calendar, check the house inventory, and be informed regarding the weather. For example, notifications can be received about their daily meetings based on the current time. Furthermore, the resident is able to view today's news, view and edit the to do list. The resident is also able to view and edit their blank notes which could be paintings and free drawings. Finally, the resident is able to view and navigate through their multimedia (Figure 40).

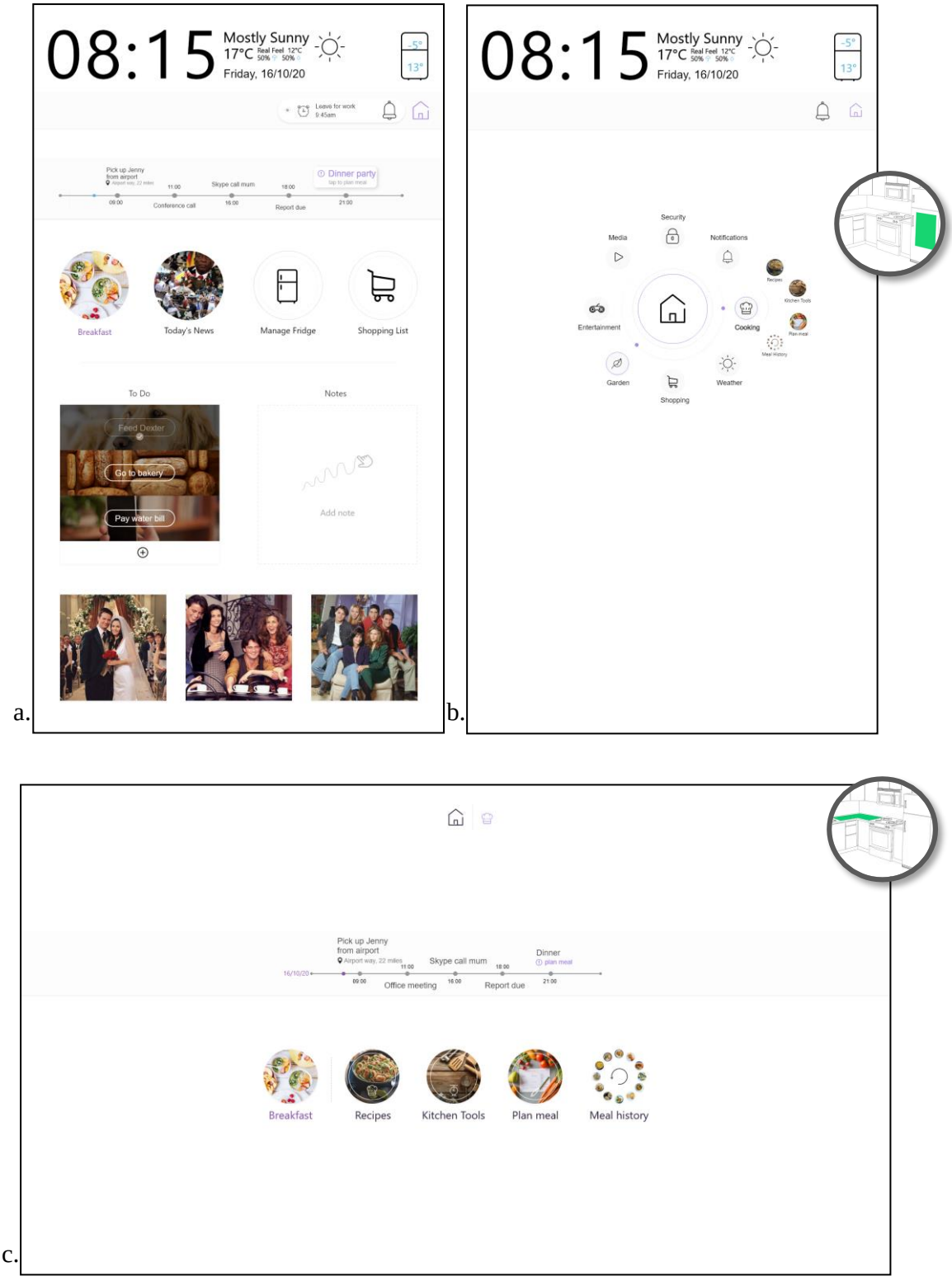


Figure 40: a. Fridge home screen, b. Fridge global home menu and c. Countertop global home menu access

Home Notifications

Residents are able to receive notifications regarding the entire home and manage them accordingly. In Figure 41, the resident is able to view the notifications from the garden of the intelligent home and from cooking. They are able to set a reminder as acknowledged, set a new reminder or dismiss the notifications.

Figure 41: a. Home menu notifications for home garden, b. Home menu notifications for cooking, c. Home menu notification dismiss all, d. Home menu without notifications

6.2 Cooking Modeling

The necessity of modeling a recipe emerged in the early stages of the design phase. Cooking recipes exist in different representations on different platforms and that depends on the author of each recipe. Usually, the minimum requirements that are represented are the ingredients of the recipe with their quantities and the execution of the recipe, which is usually presented in plain text. Digital attempts of recipe representation integrate more details such us execution time, servings, difficulty and numbered steps of the recipe. Our system attempts to model a recipe and create a schema with all the related modules that are needed to describe a recipe. This chapter presents the cooking ontology for the cooking process which extends the Mingei Craft Ontology (CrO) [76], as well as the authoring of recipes which is supported by the Mingei Online Platform.

6.2.1 Conceptualization

A series of brainstorming sessions has been conducted with the participation of participated beginner and advanced cooks, as well as researchers in the area of Conceptual Modeling. Five key areas were discussed: recipes, recipe steps, recipe actions, ingredients and utensils. The ontology followed a cycle procedure for its creation. Concept identification – Relationship identification – Properties identification. Through this iterative process and after a series of meetings we ended up with the major modules. Those are the recipe, recipe steps, cooking ingredients, cooking utensils. There was a continuous dialogue in the earlier phases of knowledge acquisition, and the requirements specification of the cooking ontology were re-examined. Their satisfaction was continuously evaluated by the team members.

6.2.1 The Mingei Ontology for Cooking Process Modelling

This section presents classes, properties and axioms that are part of the Mingei Craft Ontology (CrO) and are used by this research work for the modelling of the cooking process [76]. The CrO has been developed by ISTI CNR in collaboration with FORTH in the context of the Mingei project (H2020, GA No. 822336), which is exploring the possibilities of representing and making accessible both tangible and intangible aspects of craft as Cultural Heritage (CH) [77].

The CrO is an application ontology [77] obtained by integrating several existing ontologies, notably: (a) the CIDOC Conceptual Reference Model (CRM), a top ontology and an ISO standard (ISO 21127:2014) forming the conceptual backbone of the CrO ([78], [79]), (b) the Narrative Ontology, a domain ontology focused on the representation of narratives ([80], [81]), (c) the FRBRoo, a domain ontology for bibliographic records, resulting from the harmonization of FRBR with CRM [82], (d) OWL Time, a domain ontology recommended by W3C for the representation of time [83], and (e) Dublin Core for simple resource description [84].

6.2.2 Cooking Ontology

The Cooking ontology consists of the modules that are required in order to represent knowledge about a cooking process. Two main modules are the cooking recipe and the cooking step-sub steps, which contain cooking activities, cooking ingredients and cooking objects.

Cooking Recipe

Cooking recipe is the main concept of the cooking ontology. Essentially, the cooking recipe is described by sixteen attributes and a sequence of cooking steps which describes the execution of the recipe. These attributes are defined by the author of each recipe and are not all obligatory to describe a recipe.

Recipe name: The name of the recipe.

Author(s): The author(s) of the recipe.

Description: The author can give a small description of the recipe.

Cooking Steps

Cooking steps are the actual cooking steps of a recipe. They contain the following attributes.

Step name: The name of the cooking step.

Description: The actual instruction for the cooking step.

Related media object: The cooking step could include media objects such as step images and videos.

Cooking device: The cooking step could have related cooking devices.

Cooking ingredient: The cooking step could have related cooking ingredient.

Activity type: The type of activity which means the actual cooking actions that are performed in the cooking step.

Activity condition: The activity condition refers to a characteristic of the action, for instance if an activity that the user need to perform it slow or fast.

Stopping condition: If there is a stopping condition for the step.

Activity time: The activity time of a step.

Cooking Ingredients

Cooking ingredients are the actual cooking ingredients of a recipe related to a step. They contain tree main attributes.

Ingredient name: The name of the ingredient.

Ingredients details: The ingredient details could be

- **Quantity:** The quantity of the ingredient as a number.
- **Quantity type:** The type of the quantity for example grammars, teaspoon, piece, etc.

Note: The note could refer to a characteristic of an ingredient such us a “small” potato.

Cooking Utensils - Devices

Cooking utensils are the actual cooking utensils of a recipe related to a step and an action. They contain the following attributes.

Device name: The name of the utensil - device.

Description: The author could give a small description of the utensil - device.

Device type: The type of the utensil - device.

Related media objects: The utensil - device can include media objects such us images and videos.

Steps execution order

In order to apply a sequencing in the recipe steps, we introduce four order options.

Goes to step: This order option connects the chosen cooking step with the step that comes next.

Waits for: This order option connects the chosen cooking step with the cooking step that it waits for and then with the next step that is in order to be performed.

Furthermore, the CrO contains several other classes for better categorisation of recipe related information and modelling, but also for modelling the relation of the recipe's execution with objects and ingredients. These include:

- **Categorisation**
    - **Diet_Category_Type**, modelling different diet types that compose recipes (Vegan, Pescatarian, etc.), is a sub-class of CRM class E55 Type.
    - **Recipe_Category_Type**, modelling categories of a recipe (breakfast, lunch, etc), is a sub-class of CRM class E55 Type.
    - **Recipe_Origin_Type,** modelling geographical origin of the recipe, is a sub-class of CRM class E55 Type.
    - **Cooking_Activity_Type,** modelling the type of activity which means the actual cooking actions, is a sub-class of CRM class E55 Type.
    - **hasDietCategoryType**, sub-property of P2 has type, connects a recipe with Diet_Category_Type, so the domain of this property is the class recipe and its range is class Diet_Category_Type.

- **hasRecipeCategoryType**, sub-property of P2 has type, connects a recipe with Recipe_Category_Type, so the domain of this property is the class recipe and its range is class Recipe_Category_Type.
- **hasRecipeOriginType**, sub-property of P2 has type, connects a recipe with Recipe_Origin_Type, so the domain of this property is the class recipe and its range is class Recipe_Origin_Type.

- **Description of objects**
  - **Cooking_Device**, modelling devices that are used in a recipe step, is a subclass of CRM class E57 Material.
  - **Blender, Bowl, Cracking_Device, Cutlery, Draining_Device, Drying_Device, Grinding_Device, Kitchen_Utensils, Kneading_Device, Oven_Pan, Pan, Peel, Peeling_Device, Pot, Pressure_Cooker, Roasting_Pan, Weighting_Device**, all are subclasses of Cooking_Device.
  - **P68_foresees_use_of**, identifies an E57 Material foreseen to be used by an E29 Design or Procedure, so the domain of this property is class E29 Design or Procedure and its range is class E57 Material (superclass of Cooking_Device)
- **Ingredients**
  - **Cooking_Ingredients**, modelling ingredients of a recipe/recipe_step, is a subclass of CRM class E57 Material.
- **General properties of the recipe**
  - **hasEstimatedServings,** subproperty of P43 has dimension, connects a recipe with E54 Dimension, comprises quantifiable properties that can be measured by some calibrated means and can be approximated by values, so the domain of this property is the class recipe and its range is class E54 Dimension.
  - **hasDifficulty**, subproperty of P43 has dimension, connects a recipe with E54 Dimension, so the domain of this property is class recipe and its range is class E54 Dimension
  - **hasNutritionFactDimesion**, subproperty of P43 has dimension, connects an E73 Information Object with E54 Dimension, so the

domain of this property is class E73 Information Object and its range is class E54 Dimension.

- **hasExecutionTime**, data property connects a recipe with a numeric value, so the domain of this property is class recipe and its range is xsd:float.
- **hasWaitingtime**, data property connects a recipe with a numeric value, so the domain of this property is class recipe and its range is xsd:float.
- **hasBakingTime**, data property connects a recipe with a numeric value, so the domain of this property is class recipe and its range is xsd:float.
- **hasEstimatedDuration**, subproperty of P43 has dimension, connects a recipe or recipe step with E54 Dimension, so the domain of this property is class recipe/recipe_step and its range is class E54 Dimension
- **hasActivityTime**, data property connects a recipe_step with a numeric value, so the domain of this property is class recipe_step and its range is xsd:float.
- **hasOutcome**, connects a recipe or recipe_step with cooking ingredients, so the domain of this property is class recipe/recipe_step and its range is class Cooking_Ingredients.

6.2.2 Recipes Authoring

In this work, the authoring of recipes is supported by the Mingei Online Platform. MOP is an authoring platform for the semantic representation of cultural and socio-historic context encompassing a given, focal, topic of interest, such as a Heritage object, collection, site, or practice. The authoring platform has been created in the context of the Mingei H2020 project that is exploring the possibilities of representing and making accessible both tangible and intangible aspects of craft as Cultural Heritage (CH). Currently, the platform is publicly available under the link www.mop.mingei-project.eu.

MOP is developed on top of Research Space (RS) [85] a CH research platform, which provides an integrated environment for contextual data and tools designed to reflect research methods. Using Semantic Web languages and technologies, the innovations of

the system are shaped by a social conceptualization of the graph-based representation of information. This is employed by integrated semantic components aimed at subject experts that offer mechanisms to create, annotate, assert, argue, search, cite, and justify data-driven research and delivers a wide spectrum of features supporting research [86].

Authoring Basic Knowledge Elements

The authoring of basic knowledge elements regards objects and ingredients that will be used for authoring recipes. To this end, these can be considered as existing prior knowledge of the system and could be employed across recipes. Of course, there should be always the provision to add a new tool or ingredient on the fly. Thus, the extensions implemented in the MOP support the authoring of devices and ingredients. The authoring of cooking devices in MOP is quite straightforward, as it entails the provision of a name and a description the identification of device type for classification and the definition of related media objects for visual identification (Figure 42).

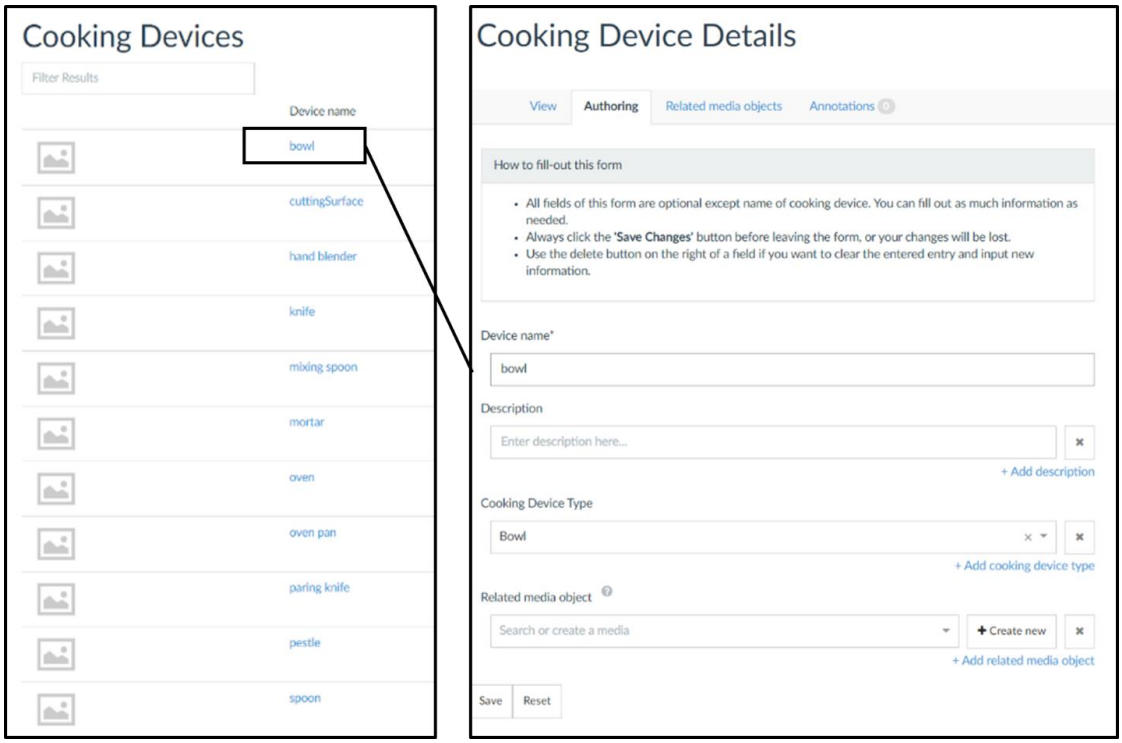


Figure 42. Authoring of cooking devices

Cooking devices are more unlikely to change in relation to cooking ingredients. These are more closely dependant on the recipe and are used both to describe initial ingredients but also outputs of recipe steps (e.g. a cream creating by mixing cheese and

mastic drops). So, ingredients are meant both to be authored prior the authoring of a recipe but also be generated during authoring, as new steps and sub-steps generate intermediate ingredients that will be subsequently used as input to next steps of the recipe.

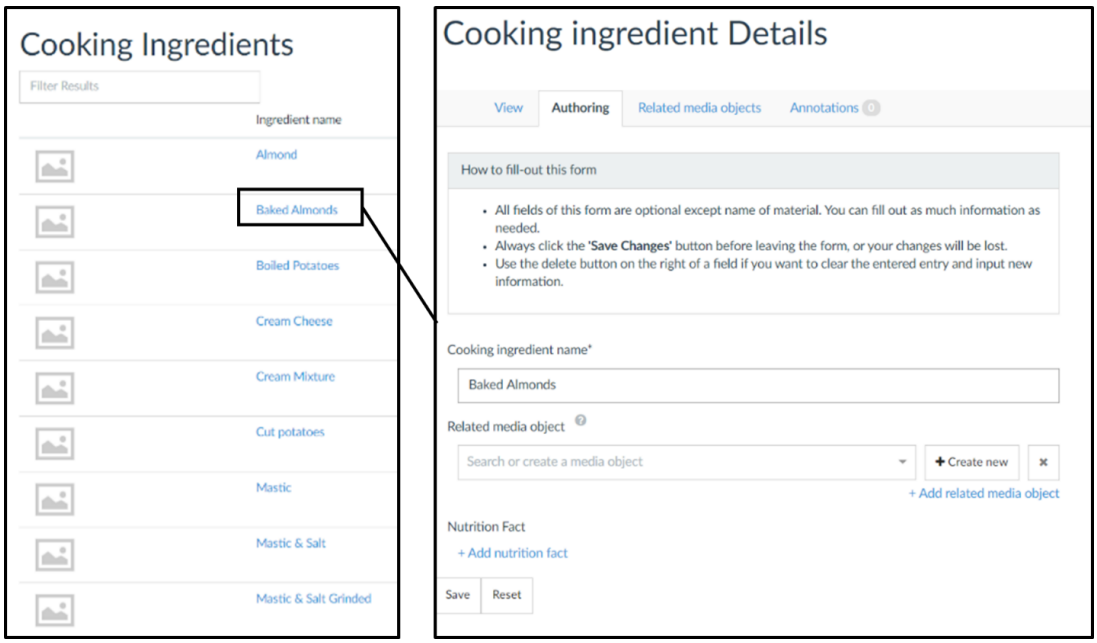
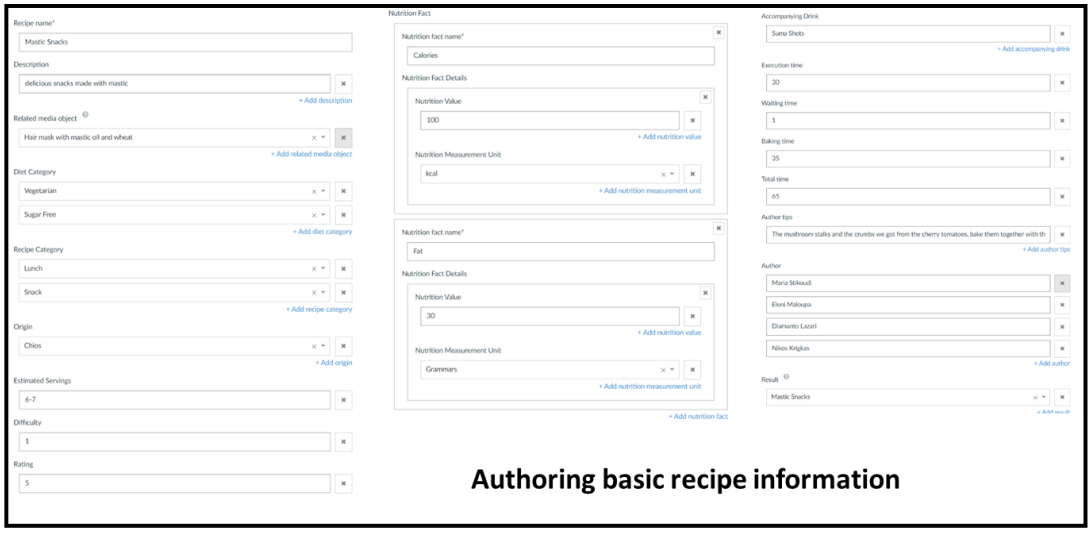


Figure 43. Authoring of cooking ingredients

Authoring recipes

The authoring of recipes happens through simple form filling operations. The main information about the recipe is inserted in the form and regards the specialisation of the recipe instance through properties and instances of the recipe model (Figure 44). The most important step for producing a machine-interpretable semantic representation of a recipe is the creation of its schema. Schema authoring is performed by identifying the steps of the recipe and then decomposing steps to sub-steps. Top-level steps can be defined in parallel to the authoring of basic recipe information as presented in Figure 44 (bottom).



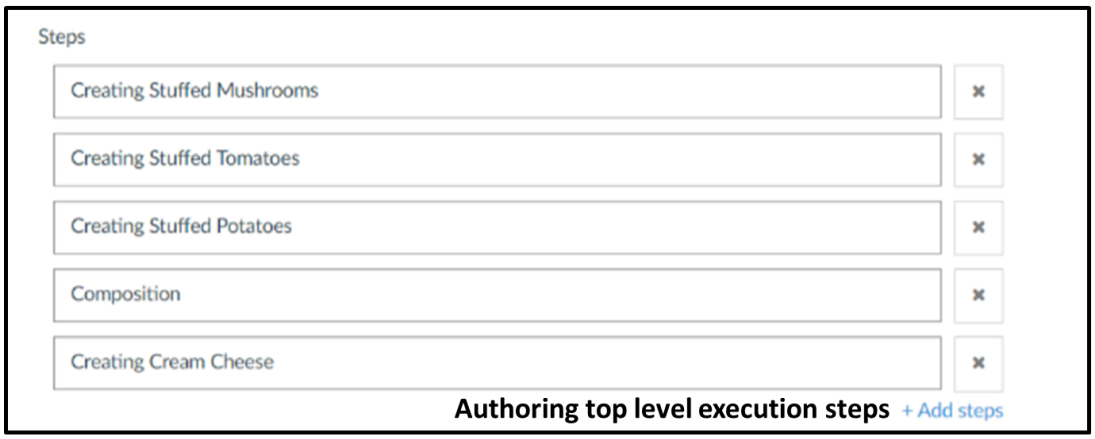


Figure 44. top: authoring basic recipe information, bottom: definition of top-level execution steps

After the creation of the recipe, the schema of its execution is defined. To do so, each recipe step should be decomposed if required into sub-steps and the relations between steps and sub-steps should be defined. This is accomplished through the authoring form for each of the steps of the recipe as shown in Figure 45 right. From this form, sub-steps can be added and for each of them, and the condition upon which the execution moves to the next step can be defined (Figure 45 bottom left).

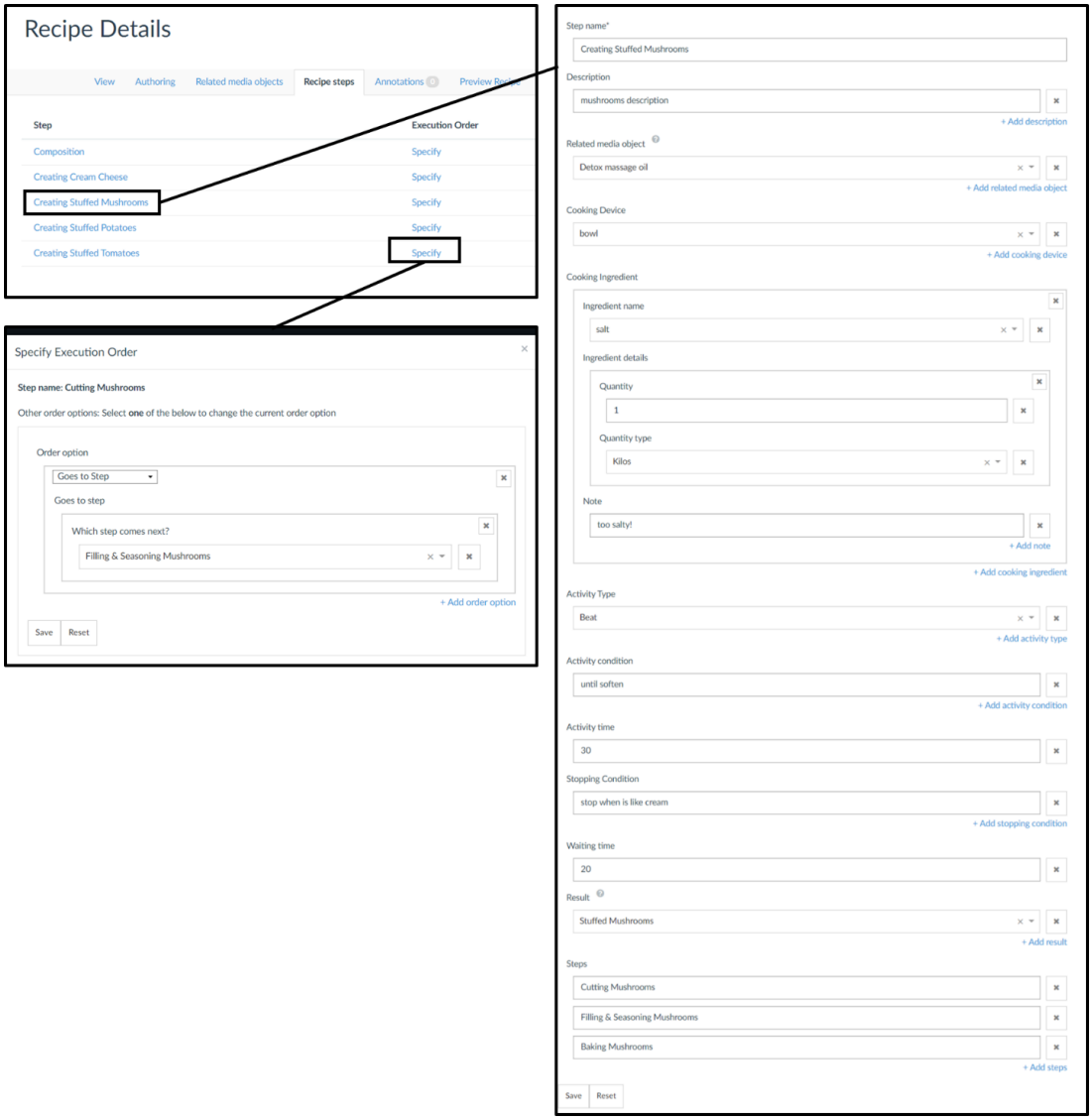


Figure 45. top left: the sub-steps of a recipe or recipe step, bottom left: execution order for a step, right: Recipe steps authoring and

When the authoring is completed, recipes can be previewed by selecting their name from the recipes list. This results in a web page that present basic information about the recipe (Figure 46 left). The execution schema can be accessed by selecting the preview functionality. From there the executions steps can be previewed, including their sub-steps and ordering options (Figure 46 right).

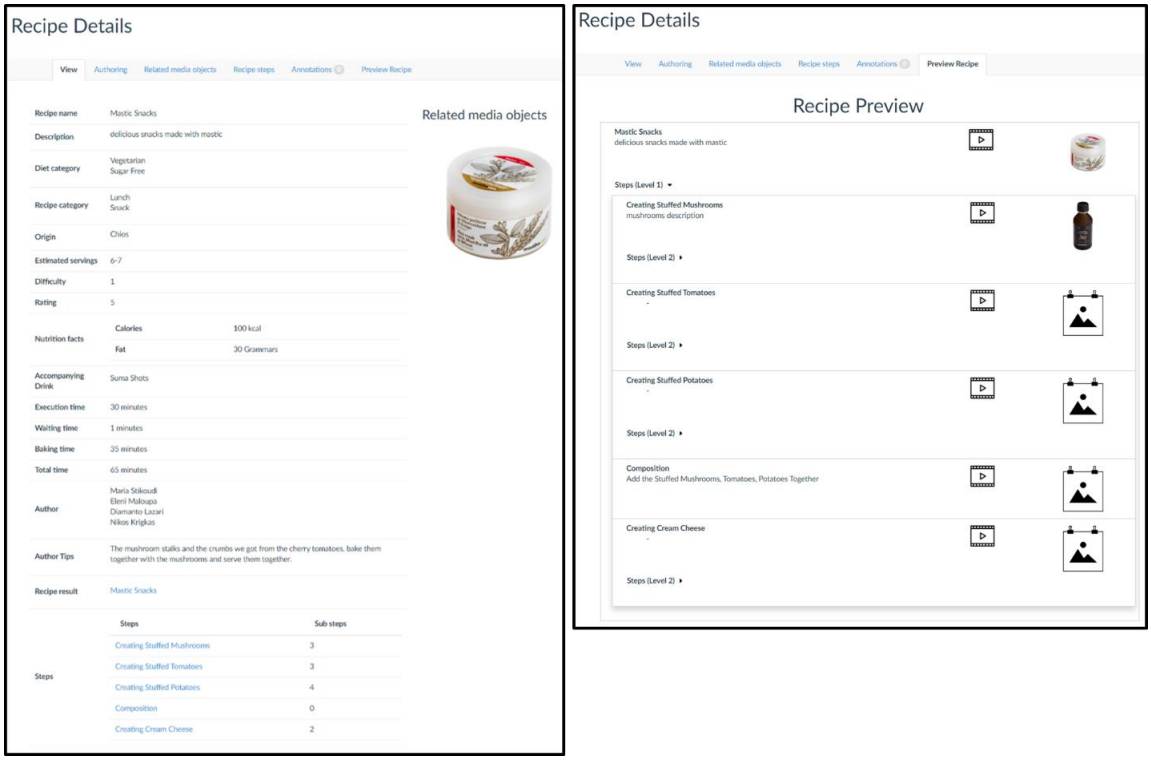


Figure 46. left: recipe details preview, right: recipe schema preview

6.3 System Architecture

6.3.1 From Mingei online platform to AmIChef

The modeling of a recipe, while being the fuel for AmIChef's functionality, cannot be used in this form. The recipe models a more generic approach of the cooking process that is agnostic with respect to the kitchen setup. AmIChef contains a small service, called recipe converter, which converts to a recipe model tailored for the kitchen where it will be executed. In more detail, it uses a generated JSON [87] as an input, that describes the recipe, and enriches it with data specific to the Intelligent Kitchen. That way, AmIChef can consume a recipe that is closer to the information that AmIChef needs, in order to provide the appropriate information for each step of the recipe process to the user.

6.3.2 AmIChef Architecture

AmIChef uses multiple displays distributed across the kitchen environment that need to be synchronized and present appropriate data based on user activity. To that end, AmIChef employs the AmIChef Core and the Data Services. The AmIChef Core represents the brain of AmIChef, meaning that it manages the recipes, the state of each

recipe and contains all the decision mechanisms required for supporting the cooking process. The AmIChef Core takes advantage of the AmI-Solertis system to receive contextual data in a unified way from different services of the home and kitchen environment, which include user profile, user schedule, nutrition habits, and preferences. The Core service processes those data to make decisions on what information should be presented to the user. For example, if a resident enters the kitchen environment and it is time for their dinner, the Core service receives this information from the AmI Environment. Taking into consideration those parameters, as well as currently active displays, the Core's decision mechanisms dictate the different displays to launch appropriate UIs with the specified content. Data services are services that wrap the data stored in the database and expose them through an API to the AmIChef Core as well as the front-end. (Figure 47) and (Figure 48) presents a graphic representation inside AmIChef.

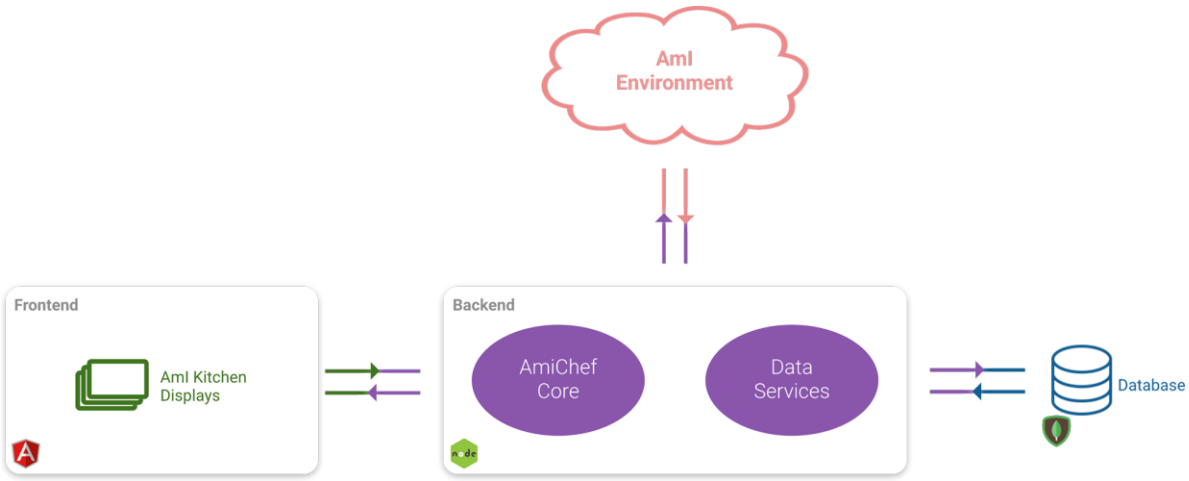


Figure 47: High-level System Architecture

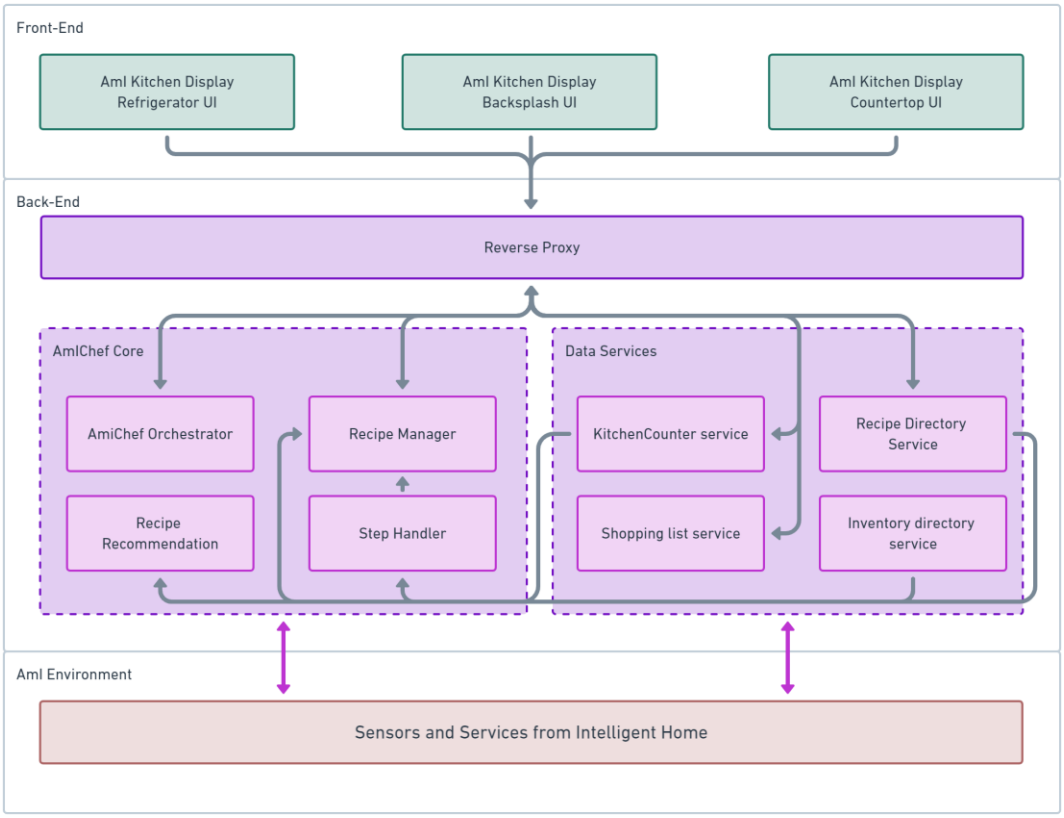


Figure 48: AmIChef Architecture

Front-end Development

The AmIChef User Interface (i.e. front-end) has been developed using the Angular framework [88]. In more detail, all the different clients for the devices (i.e. AmIBacksplash, AmICountertop, Refrigerator) that AmIChef uses are under the same Angular project. With this approach, AmIChef takes advantage of the Angular services to share common logic and data across the different User Interfaces without the need to implement them separately. Moreover, components that are similar among the clients are implemented only once and used by each separate client. Each client consumes the APIs of the data services in order to receive all the required information for presenting the suitable views (such as recipes, availability of utensils and ingredients for a given recipe, and recipe step status for the cooking process). In addition, client synchronization is achieved through the AmIChef Core, where each client subscribes to an event mechanism in order to listen for events regarding the state of the cooking process.

Back-end Development

The AmIChef's backend has been developed using Node.js runtime [89]. The reasons behind using Node.js for the implementation of the backend are that (i) it uses JavaScript, which is the same language used for implementing the front-end part, allowing for sharing code between front-end and back-end development while the processing of data is the same, removing issues while exchanging messages and (ii) it is reliable and ideal for creating robust APIs.

The backend follows a microservice architecture. A plethora of different services are implemented, encapsulating parts of the functionality of AmIChef. Services are loosely coupled and each one is bound by its context and is agnostic about the other services. In order to provide the appropriate overall functionality, services exchange messages with each other through an event broker. Subsequently, each service only has to subscribe to the event broker in order to be informed for new data and state changes. Whenever a service performs an action, it publishes a message to the event broker and services subscribed to the event broker for the given event can consume it and perform any needed actions.

AmIChef Core

AmIChef Core provides its functionality through multiple services described below.

The **Recipe Recommendation** service is responsible for checking the inventory of the kitchen in order to decide if a recipe can be prepared with the ingredients currently in the kitchen. It can suggest recipes based on contextual data such as the time of the day and the occasion, based on information provided from the calendar service. For example, if it is 16:00 o'clock and the user is waiting for two guests for the evening, it will suggest dinner recipes, containing available ingredients, for three servings. Moreover, if diet information is available for the guests, it will suggest recipes that are appropriate for their diet preferences. A simple algorithm is used based on if statements with the current information of the specific time in the day.

The **Recipe Manager** is responsible for keeping track of a currently running recipe. Additionally, it manages the flow of the recipe, deciding if a step can start or is completed and which step should be performed next, after a step is completed.

Moreover, whenever a step contains a process like baking, it determines whether another step can be performed by the user while the process takes place (e.g. the kitchen is roasting and the user is free to continue with preparing the sauce).

The **Step Handler** is responsible for managing data for each step. The Recipe manager contains an instance of the step handler for each step of the recipe. The Step Handler contains specific information about the state of a step. It knows the exact status (i.e. not prepared, collecting ingredients for the step, preparing the step, waiting for a time-consuming process such as baking to continue with the rest of the step, or completed). It keeps track of the ingredients, tools, and utensils needed for the step, as well as the current status for each of them (i.e. if it is not collected from the inventory, if the amount is less or more from what is needed for the step, or if it collected and ready to use).

The AmIChef Orchestrator is responsible for the synchronization across the different devices. Through an event federator mechanism, it communicates with the different devices in order to orchestrate them and to provide a seamless experience to the user by unifying and harmonizing the overall experience. In detail, to achieve the synchronization of the devices, it uses an event system, where the AmIChef clients are listening for messages. In case that an action occurs in one client, that affects a different client, the orchestrator informs the other device about the action through the event system. Moreover, during the cooking process, the orchestrator dictates through events the state where each client should be at any given time. For example, if a step is completed, it will dispatch an event to let all of the clients know that a step has been completed and to proceed to the next one.

Data Services

Data services expose their functionality through a restful API. They are stateless providing no logic other than serving the data from the database and endpoints that allow to store and edit the data of the database. The list of the different data services is described below.

The **AmICountertop service** contains the status of the countertop. It stores the ingredients, utensils and tools that are present on the countertop as well as their position

and amount. The data are generated from an object recognition system for the countertop as well as the countertop's integrated technology.

The **Recipe directory service** stores and provides all the different recipes available in AmIChef. It allows for filtering recipes through variables such as diet, ingredients, and occasion. Moreover, it can provide the different amounts of ingredients needed for a recipe based on the total services, which is dictated by the recipe model. The amount of the ingredients needed is not simply a multiplication of the ingredients for one serving to the total servings. It is more complicated and the ingredients that their amount changes based on servings differ from one recipe to another.

The **Inventory directory service** contains and provides information about the ingredients, utensils, and tools that the kitchen contains. Additionally, it is responsible for tracking where each item is placed in the kitchen. This service is consumed by the AmIChef Core in order to determine if the ingredients needed for a recipe are available in the kitchen, as well as to guide the user in the ingredient collection process.

The **Shopping list service** is a simple service that contains a list of ingredients. It can store ingredients as well as an amount for each one, and is used to store ingredients that a user wishes to buy in order to restock their kitchen or to be able to cook a recipe.

Chapter 7
Cognitive Walkthrough Evaluation

A cognitive walkthrough evaluation experiment was held to evaluate AmIChef, with the participation of three (3) User Experience (UX) experts. The objective was to evaluate the general idea and its potentiality, identify any unsupported features and reveal potential usability errors by noticing the remarks and general assessment of experts prior to arranging an extensive user-based evaluation experiment. The cognitive walkthrough method is used to examine the usability of a user interface and the degree to which an interface is self-explanatory, meaning how easily can new users interact without formal training [91]. Its purpose is to identify whether or not a user can easily perform specific tasks within a given system. The nature of the cognitive walkthrough defines it as one of the fastest forms of usability testing compared to many other evaluation methods, since the user is only required to carry out small tasks. The method is ideal for use prior to development and during the design phase of a system.

7.1 Process

During the experiment, a conductor helped the users (UX Experts) to work through a series of tasks and asked them a set of questions to understand how simple it is to interact with the AmIChef workspaces. The conductor observed a series of user actions and gathered notes regarding whether they tried and achieved the desirable outcome, whether they perceived that the correct action is available to them, and that the outcome of the action was the expected one. Finally, when the experiment ended, the conductor documented the steps that seemed to confuse the users, as well as the issues that emerged.

7.2 Results

Experts argued that the system satisfies the requirements, supports effectively the cooking process and users can successfully accomplish the desired result. Experts achieved the right outcome through the tasks and associated the correct actions with the outcomes they expected to achieve. They noted that they mostly felt confident about

their actions, they were aware about the current state of the system, and that the system feedback was appropriate and reassuring throughout the whole cooking process. The most notable issues that were identified from the evaluation process, along with the proposed solutions, are listed below:

Issue 1: AmIChef's interface is distributed across multiple displays. Given that users are not used to navigate through multiple displays simultaneously, when they perform an action, they tend to focus only on one display at a time. This can cause users to miss information that is not displayed in their current field of view.

Solution: An approach to solve this issue is to navigate the user's attention through animated indications from the current point of view to the display that the change occurs. With that kind of indication, the user's cognitive load is expected to be lowered, as they will not have to remember on which display the result of an action occurs.

Issue 2: AmIChef detects when a recipe step is completed, and it automatically advances to the next step of the recipe. One of the users commented that they would prefer to be able to manually advance to the next step. They prefer to have control over the system in order to be able to follow their own pace.

Solution: The system will support a personalized preference (as an addition to the current cook profile of the user) where the user can set if they would like to automatically advance to the next step whenever the system detects that a step is completed or to manually control the recipe steps. Following the latter approach, the system will indicate if a step is completed or not, and the user will be able to proceed to the next step through a dedicated button on the countertop.

Issue 3: AmIChef provides all the required information about a step that residents will use in order to complete it. The information is distributed across multiple displays. Due to the complexity and the plethora of information that the recipe step contains, a user can be overwhelmed. A user who is not familiar with multi-device interfaces and uses AmIChef for the first time, could be confused but after getting used to how the information is distributed across the devices, this issue is no longer relevant.

Solution: To provide a solution for this issue, AmIChef will integrate a quick start guide for first time users, to introduce them to the User Interface (UI) and explain the

overall functionality. The guide will indicate areas of the UI for each display, informing users about their purpose. An alternative approach would be to minimize the information presented in all displays down to the bare essentials for each step of the recipe and subtract any information that might compete for the user's attention.

Chapter 8
Conclusion & Future Work

This thesis has presented AmIChef, an assistive cooking system that aims to support the residents of Intelligent Homes by providing interactive, context aware, multi-modal, multisensory, user-adaptive, and intuitive assistance for meal preparation. AmIChef will be integrated in the technologically enhanced kitchen of the ICS-FORTH's Intelligent Home. This Intelligent Kitchen is equipped with common kitchen appliances and devices, as well as custom-made artifacts with embedded displays and sensors (e.g. smart countertop, smart backsplash).

AmIChef's goal is to support the entire cooking process effectively (i) during the cooking planning actions and (ii) during the preparation of a meal. To that end, it offers distributed user interfaces through the kitchen environment with multiple interaction modalities that aim to aid the resident in a non-intrusive way. Moreover, AmIChef is by design considering the fact that during the cooking process the resident has to perform an abundance of tasks simultaneously and their hands may be occupied while performing an action that might be time critical.

Based on the cognitive walkthrough evaluation experiment that was conducted, AmIChef seems to be a promising cooking assistant. Experts seemed satisfied about the assistance that AmIChef offers and the way that the system guided them to the desired result. They noted that AmIChef made them feel confident and that they would be able to execute the recipe even if they have never prepared the same recipe.

When it comes to the discussion of future work, there are some improvements and additions that could be done. First of all, addressing the issues that emerged from the cognitive walkthrough will make possible a large-scale user-based evaluation in order to further evaluate the system.

Future work contains new additions to the system. The cooking support aspect of AmIChef will integrate the option of video calls in case that a user needs specific

assistance from a person (e.g. parent). Another addition would be the recording of the process for future reference, as well as to be used as a video guide that can be shared to aid another user (e.g. parents to their child). Another potential extension of AmIChef is the cooking process with multiple users performing actions in parallel in the kitchen environment.

Finally, regarding the interconnection with the rest of the Intelligent Home, AmIChef will provide options to supervise and manage easily the entire home through the extension of the display information on the AmIBacksplash and AmICountertop.

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Appendix A
Acronyms

AmI Ambient Intelligence

BR Behavior Reasoner

ICT Information and Communication Technologies

IM Intervention Manager

IOT Internet of Things

IP Interventions' Pool

LC Learning Component

SAL Sensor Abstraction Layer

SUS System Usability Scale

TAP Trigger-action programming

UI User Interface