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Robot-Supported Food Experiences
Exploring Aesthetic Plating with Design Prototypes

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Abstract. Robots are increasingly taking up roles in society to support and interact with humans in various contexts including the home, health-care, production and assembly lines, among others. Much of the research focuses on efficiency, speed, accuracy of repetitive tasks, and in most cases the robot simply replaces and performs work tasks originally performed by humans. Looking beyond the simple replacement of humans with robotic servants, we focus on increasing creativity and pleasurable experiences supported by robots for the preparation, serving and consumption of food. This is a culturally rich area to design for, which is steeped in tradition, social norms and expectations. How can robots play a role in this context? We observed and interviewed chefs to gain a sense for opportunities for robotic technologies. We then created nine exploratory video prototypes involving food preparation with a robotic arm taking departure in themes of haute cuisine, "plating", and the arts in order to show some of the capabilities of robots and to spark their imagination for possible future uses of robots in the kitchen. Through questionnaires and interviews, we gained feedback from ten chefs with resulting themes including harsh criticism and resistance to robots as well as desire and interest for robots to support food experiences as a partner in the restaurant. We discuss emergent themes from the feedback and provide discussion on future work needed to explore robots as partners in creative contexts.

1 Introduction

Robots are finding roles as visible actors alongside people across society from supporting surgeons in the mission critical surgical theatre [35] to providing comfort as a virtual companion [15]. These roles go beyond the traditional view of robots acting as replacements to humans or acting as a servant, toiling away in the background. Even in the industries most heavily relying on robots for production, such as the automotive industry, there is an increasing shift in perspective toward a more collaborative approach with robots working with humans appearing in various forms [43]. Going beyond the focus on sequential, repetitive work, and simply replacing humans, there are examples emerging in the home and service sectors including food and beverage, in which robots take up supporting roles, acting

with some degree of social awareness [24]. Moreover, researchers have examined the close contact of humans and robots and the attitudes and feelings evoked by robot companions [45]. Researchers have signalled emerging and evolving culture and new attitudes around robots in society as not only passive artifacts, but as partners in human activities and creators of culture [38,40].

In the food industry, an ongoing concern has been that with more technology and standardization, there can be negative effects from deskilling chefs, staff reduction, reduced labor mobility, and job losses [36]. In a recent opinion report by the European Commission that reached out to more than 26,000 people across 27 member nations, there are wide differences in opinion within EU citizens regarding where robots are welcome in society and sectors in which people believe robots should be banned [8]. In that report, a common theme was identified in that robots were viewed as suitable for utilitarian purposes and dangerous environments, but not welcome in the more 'human' contexts such as caring for the elderly or taking care of children. While the survey is helpful identifying some of the popular opinions, it is unclear how people form their beliefs about the capabilities of robots. It is the aim of this paper to engage more closely with people in the food industry to gain a sense for their attitudes and opinions about robots and ways they imagine robots in the food industry. Our inquiry is inspired by the perspective of 'co-design' that aims to involve specialized users and develop solutions that fit into existing practices and uncover unmet needs [41]. We feel it is necessary to reach out to chefs to examine how we might co-design experiences for the future kitchen with robots, not to accelerate a reduction in the workforce, but to look for opportunities for new experiences and uses for robots as collaborators.

The focus of this paper is to explore and shed light on how robotic agents can be implemented in the modern gastronomical kitchen as a collaborator, assistant, or an extension of the chef. The paper is guided by the following important questions regarding human-robot interaction and collaboration: *How can robots support and enhance desirable experiences related to the preparation, serving, and consumption or sharing of food? How can the design of robot-supported experiences related to food benefit from existing knowledge, attitudes, and techniques of people in the food industry?*

The structure of the paper is as follows: we briefly highlight and discuss some of earlier and current work within the food industry and the research of robots supporting preparation of food, next we describe our research through design approach including the empirical work along with the development of the exploratory design prototypes. We then discuss the results of our work in terms of emergent concepts and ideas based on preliminary findings and impressions from chefs. We highlight two perspectives on the envisioned roles and visibility of robots and food experiences. Lastly, we present emerging ideas and highlight interesting future work.

2   Related Work

There is a long history of research and invention involving robots in the food industry. We review some of the ways robotic technologies have been introduced

and relevant points raised by the research community. Of particular interest are the opportunities and challenges for human robot collaboration and research that has called for more culturally meaningful ways to involve technology and food experiences.

A cursory search through a patent database yields many examples of robots and automation technologies in the food industry. In the patent details for a robotic cooking system described in [14], patents describing automated tools for handling ingredients and preparing food were appearing as early as the 1920s. There are many examples of robots in the food industry which focus on efficiency and speed of repetitive tasks, packing vegetables [6], mixing components, and other tasks that would normally be performed by a human worker [46]. Contemporary manufacturers including Universal Robots, ABB and others advertise capabilities of their robots being able to deliver non-stop productivity with a reduced risk of employee injury by offloading repetitive tasks [1,7] - providing the benefit of productivity and safety to the production line.

There are various examples of technology designed around food including smart kitchens, augmented utensils, and design of culturally sensitive robot experiences with food [30]. There have been cooking and serving robots developed for assisted living facilities in which elderly people are confined to wheelchairs [31]. More recent examples include the use of robotic arms to assemble and cook ingredients for simple dishes [37] and more advanced robotic arms that can record the movements and techniques of the chef and make them available for replay through an online content store [33].

In terms of collaboration, there are examples in which researchers envision real-time cooperation with robots without relying on preplanned tasks. Shah et al. [42] presents a system for optimizing human-robot team performance by letting the robot more naturally emulate the decision processes of human teams. This is particularly important in the kitchen, which is a very dynamic context and the handling of food ingredients and dishes require great positional accuracy and context awareness [48]. There has been research on robots performing a variety of dynamic tasks within the kitchen, such as a task planning system for collaboration between robot and human [27] or recognizing human activity in a cooking context, in order for a robot to better support and guide future actions [25].

Researchers proposed metrics for human-robot interaction including performance measures, but also social and aesthetic experiences [44], yet there are few examples of research exploring robots and the creation of aesthetic experiences around food. Whether it concerns preparation or consumption, it is important to note the difference of solving existing problems with technology or augmenting current practises within the kitchen. There has been an increased interest in interactions related to food in the human computer interaction research community [16]. Grimes and Harper [28] suggested a shift in focus from corrective technologies to enhancing existing experiences and practices through more emotionally relevant measures. *CoDine* provides an inspiring example of robotic technologies designed to connect remote diners in order to share dining experiences and communicate in and around food [47]. We appreciate their focus on using robotics to support "...experience over efficiency and shared interaction over information."

3   Research Problem

While there are various examples of robots supporting the preparation and dispensing of food or drinks, the focus in much research has been largely on replacing the human chef or server to bring improvements of speed and efficiency. Our focus is not on solving current problems linked to efficiency, but instead our goal is to explore and imagine how robots can support aesthetic and pleasurable experiences with food, and support the creative process in the kitchen. Much of our daily life revolves around preparation of meals and the topic could be rigorously reviewed and explored in various directions. In this work, we are not interested in optimizing a known design or prototype, but rather to engage in a design exploration to find points of divergence and possibilities for future inquiry. To narrow the focus of the research we report here, we are guided by the question, *How can robots support chefs and serving staff in the design of experiences with food?*

4   Method

We adopted a research through design approach [26] in order to begin to explore the design space of robot-supported food experiences. We first immersed ourselves into the context of the kitchen with observations and interviews with chefs. We then developed simple experience prototypes involving the placement and preparation of food. We shared these with chefs and asked them to answer questionnaires and take part in co-design interview sessions to imagine possible uses for robots in supporting experiences with food.

Our investigation recognizes the difficulty in designing new technologies for situations in the real world. We do not want to over simplify the design space and we recognize that singular cases are not generalizable across cultures. In the context of food preparation and serving, there are many practices and concerns of chefs that are culturally significant and do not necessarily need to be changed. Our focus is not to remedy known problems, but to explore the design space and uncover potential opportunities for robotic technologies. As such, our inquiry is an attempt to empathize with the practices, struggles and concerns of chefs. We hope to re-frame the understanding of how technology can support the existing creative context [17]. This paper represents the initial attempts to engage with chefs and imagine some ways in which robots could become useful partners in the kitchen. We take inspiration from co-design workshops in which researchers provided farmers experiences around robotic technologies so that the farmers would have deeper insights into the technical possibilities of robots and more quickly imagine a future with robotic tools in the field [20]. In a similar way, we wanted to educate the chefs on robotic technologies and capabilities, but we needed to respect the limited time the chefs had to work with us. We conducted interviews with Danish chefs formally trained in the French tradition of cooking, observed their kitchens to gain insights into their ways of working. Themes that emerged from the initial investigation resonated with some of the

elements from fields of art, architecture and theatre and helped to guide the design of nine video prototypes involving the creation and manipulation of food with an ABB IRB120 robot arm [9]. We focused on how the interaction between chef and robot could augment and enhance the creative process. We included examples that highlight unique capabilities of robots and computational support. We showed the video prototypes to ten chefs and waiters and asked for their feedback through a questionnaire and invited them to imagine ways robots could be designed to support them in their work and in the food industry in general.

4.1   Observations

In order to gain a deeper understanding of restaurant kitchens and the work routines within, we conducted three observation and interview sessions. One at a hotel restaurant and the other two at a team-cooking kitchen. Through these sessions, we identified different work processes, goals and agendas unique to the respective kitchens, one focusing more on serving for public diners and the other focuses on the collaborative cooking process. In the observations, we used jotted notes and although we were permitted to ask questions during the observation, we kept these to a minimum and instead reviewed questions and obtained clarifying details from the head chefs after each session during the semi-structured interviews.

The hotel restaurant kitchen was observed at noon, during preparations for the evening and serving à la carte lunch. The head chef's staff consisted of nine chefs with specific roles ranging from grill chef, vegetable chef to pastry chef and various chefs who fill in as needed (roundsman). However, as the staff was urgently preparing ingredients for the night's dishes, more of the staff assisted where needed and took on the role of a roundsman. The chefs were positioned at different stations, e.g. one chef was preparing scallions by peeling them, another prepared meat. The communication was limited to prosaic conversations and small discussions about the ingredients and preparation. The shared knowledge of what each chef was doing predominated the work flow, as one chef would only come over to assist another chef if requested or if certain that he or she needed a extra pair of hands. During lunch, the plating was primarily done in advance with cold dishes or salads being plated at the time of order. Plating was done in layers, built in a bottom-up approach, see Fig. 1.

Fig. 1. The bottom-up arrangement of ingredients in a salad

We developed a sense for how a dish is designed through the discussions with the chefs. The composition and visual expression of a dish starts as an iterative, experimental design process, where the chefs try out different placement, patterns, and arrangement of colors. The plating can either have a specific layout, such as a seasonal color palette or more exploratory with unusual ingredients and varied textures. After an iterative process, the composition of color, tastes and texture manifests in the plating of a dish that subsequently prepared dishes should replicate. This means that a large part of the creative process in cooking, is not a continually on-going process, but rather much of the look and placement of elements is set in the initial stage of creation. Time is a considerable constraint in gastro kitchens and preparation is vital to delivering a high quality experience consistently for all guests. The chefs have to be resourceful and therefore do not experiment or try to be overly creative during busy service hours. Line cooking is predominate in busy kitchens, but the æsthetic composition of the food experience has been meticulously planned beforehand - the diners' experience of a dish is paramount. This is exemplified in Fig. 2 in which the plating has been planned beforehand and then created as copies as consistently as possible.

Fig. 2. In "plating" the chef creates the desired look for an element and then replicates it for each serving

When plating, the chef essentially creates a packaged, edible experience that unfolds as the diners take a bite. After being served, the dish is often explained by the waiter, ensuring that the diners gain an appreciation for the ingredients and the composition - the chef's thought behind the dish. The unfolding experience is a combination of tastes, textures, visual elements and sounds.

In our semi-structured interviews, we asked how they could imagine a robotic collaborator in their kitchen. The answers were focused on the more tedious parts of the job, such as repetitive work and less fulfilling tasks, e.g. when preparing ingredients or cleaning the kitchen. The chefs did not immediately consider how robots could assist in the creative aspects of exploring form and innovative plates. They did, however mention popular consumer robots, such as the iRobot Roomba [5] and the Dyson 360 Eye Robot [4]. They focused on how robots could alleviate the burden of tedious tasks of cutting ingredients, cleaning utensils and other duties that seemed to indicate they imagined robots as "automatons", well suited for executing tasks repeatedly, efficiently and precisely.

In the team training kitchen, the staff consisted of one head chef and two assistants and was observed in the evening. In one session, the head chef focused on teaching a dish and its variations to amateur chefs, who had little experience in a professional kitchen. In another session, the kitchen held team-building exercises by grouping a set of colleagues and having them work together within the kitchen with the final dish creation being a shared responsibility. In both sessions breakdowns occurred within the team due to unclear communication among the team and limited cooking knowledge, and in some cases the participants could not understand the directions given by the expert level recipe. The work was delegated and divided into sub-activities, such as cutting asparagus or opening mussels, where each person had a responsibility for a part of the final dish. The head chef's role was to inform, teach and create a cozy, helpful atmosphere. Plating was done in an ad-hoc fashion whereas the participants would simply experiment with the random placement of ingredients.

Even though the context of the two kitchens was very different, they had some similarities in the way they communicate, divide and delegate work. In both kitchens there is a strong focus on collaborating by dividing the dish up into the preparation and cooking of specific ingredients, where each chef/participant has an area of responsibility. The professional chef replicates one chosen plating of a dish, whereas the team-building participants sought to experiment in a more ad-hoc fashion.

We recognized that issues important to chefs relating to the intended diner experience and means of expression resonate with the concerns of artists, actors and architects. Instead of relegating the robot to copying prior designs, we started to recognize opportunities for the robot to serve as a creative tool for the chef. As an initial exploration, we limit this paper to the exploration and development of design experiences with inspiration from these guiding elements.

4.2   Exploratory Prototypes

We sought out to explore robots providing a role in the creation of aesthetic interactions and experiences regarding the preparation, serving and consumption of food. We developed 9 prototypes serving as an initial exploration into the domain of gastronomy and robotics and are intended to be used to stage further discussions with chefs. These examples aim to help them understand more about the capabilities of robots, how they might manipulate food and support

the dining experience. This approach of building initial experiences with new technologies and subject matter experts has been helpful in facilitating communication among the design team to support collaboration in the idea generation process [21].

Taking departure in themes from art, architecture, theatre, and insights gained from the observations and interviews, we developed 9 exploratory prototypes that utilize a desktop industrial robot to prepare food and documented these in short videos. The prototypes were created and documented in the Robot-Lab at the Aarhus School of Architecture over a period of two weeks. In this section we describe the robot platform and each of the prototypes. A compiled short video provides an overview of each of the nine design prototypes [29].

The ABB IRB120 desktop industrial robot [10] as shown in Fig. 3 was used as an experimental platform to support the design explorations. End effectors, tools, or "grippers" are typically connected to the end of the robot arm and are chosen to fit the task. In our case, however, the robot does not come from the manufacturer with specialized food handling effectors, therefore, we designed special purpose grippers and handlers using the Rhinoceros CAD application and then printed them in nylon using the EOS Formiga P110 3D printer [22]. The handling of food and recepticals such as bottles and cooking utensils required careful design work and some quick prototyping with tape, foam, and glue. Some of these custom effectors are shown in Fig. 4. The effectors were designed specifically to the task it should fulfill for example, the spatula-like gripper which can reach under food and move it, the cube-gripper designed for food-cubes that are $3 \times 3 \times 3$ cm in size, etc. Some of the grippers have been modified after being printed to optimize them for the task. The candle gripper was actually the cube gripper, however, by attaching a bit of foam to each gripper, they could grab small birthday candles firmly without crushing them.
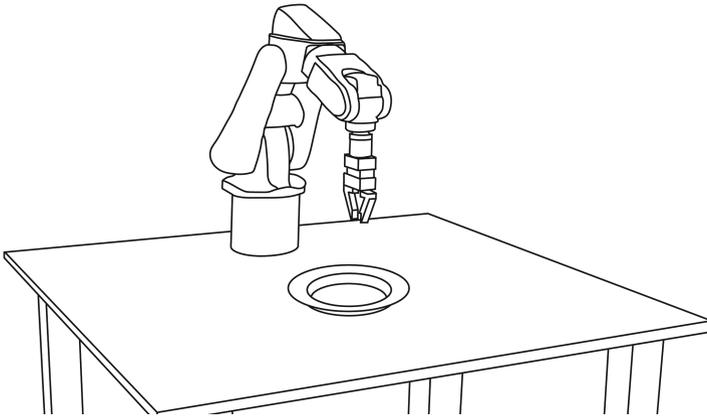

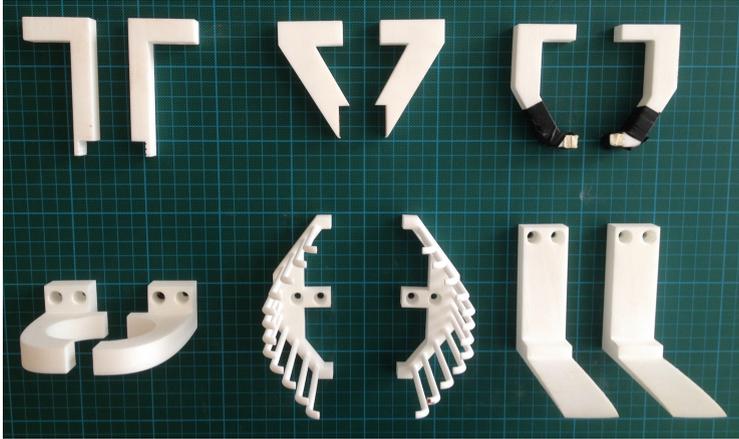**Fig. 3.** ABB IRB120 desktop robot mounted to a mobile work surface.

Fig. 4. Effectors supporting the design experiments include various grippers for handling food and food containers (1 cm scale grid)

Our process of creating and conducting the design prototypes, consisted of transforming the conceptual ideas or sketch into a specific task and series of movements, manually programming the movement of the robot and then executing compiled code on the IRB120 robot. The series of movements was created by constructing three dimensional shape of a path in a CAD program, which was then converted to a series of sequential targets with I/O signals and in between positions for smoothness of motion. These movements were then compiled to RAPID code in ABB's RobotStudio [3] and loaded to the IRB120's IRC5 controller [2] to be executed by the robot arm.

Candle. The robot is able to perform repetitive tasks with a high level of precision that creates an opposite aesthetic expression of normal dish, where the organic curves often predominate the plating. It can be seen as the culinary answer to military parades' robot-like marching, which is fascinating, simply because it seems like they posses machine-like precision. In the experiment of Fig. 5; Candle, we draw on the concept of Haute Cuisine, where the robot, carefully and with high precision, places birthday candles at varying angles along a surface and varying patterns.

Plating. Plating is an artistic process in cooking, where the chef creates the foundation for a dish, which complements the main ingredients in both color and shape. Plating is often done in full control of the chef, however we divide the control between robot and chef. In the particular experiment of Fig. 5; Plating 1, the robot creates the boundaries in which the chef can work and forces him to be creative in ways he cannot fully control himself. This is particularly interesting as it challenges the role of the headchef who normally would be plating and be in total control of how the dish is being formed. However, we don't want to

Fig. 5. On the left - Candle: Inspired by Haute Cuisine, the robot picks and places with speed and precision candles in various angles on a birthday cake. On the right - Plating 1: Here the robot creates the boundaries in which the chef has to work with the plating.

replace the headchef and make him, to some extent, obsolete, but we aim to create new ways of how two vastly different entities can collaborate and reach new heights of creativity.

In addition to Fig. 5; Plating 1, we shifted the control between the robot and the chef of how the plating should be conducted. In the example of Fig. 6; Plating 2, it is the chef who creates and decides the boundaries of the plating, wherein the robot has to operate. This is also in striking contrast to what chefs are normally used to, where they are particularly aware of how the end result should be. This is further noted during the observation at the Comwell Hotel as the Head chef stated that the very first plate to leave the kitchen, is the one to copy. Thus, by taking away their control of one of the most important aspect of service, we draw attention to how robots are to be viewed.

Painting. In Fig. 6; Painting, we are taking inspiration in the near surroundings as input and using food as output in such a detailed manner that only artists

Fig. 6. On the left - Plating 2: The chef creates the boundaries in which the robot can work. On the right - Painting: The robot takes input from the near surroundings and uses food as output to illustrate it.

can perform. In this example The painting of a face or similar can also be seen as a single, exciting experience that takes place in front of the diner - first creating confusion and afterwards surprise, after the diners participate in guessing what the robot is painting. This further enables the chef to form a more personal food experience that can unfold at the table.

Food Visuals. The chef's composition of a dish is often a fusion of the ingredients' taste and color - the combination of taste and visual expression define a cultural dish, like e.g. the overall yellow color palette of an Indian curry dish. In the experiment of Fig. 7; Food Visuals, we investigate how the robots precision and repeatability of actions can create intricate mixes and shapes of colors in food. We investigate how food coloring and geometric shapes can help the chef in discovering new ways to design dishes. The robot can either do a pre-programmed shape in e.g. whipped cream or do random shapes, whilst the chef can add different colors that outlines the shape. In the food coloring experiment, the robot becomes a tool for ideation, which helps the chef compose different colors, shapes and patterns utilizing the precision and randomization of the robot. The chef can simply let the robot control some of the parameters, whilst he maintains the ability to choose the remaining parameters, such as the colors used. This creates an interesting collaboration between robot and chef, as control is negotiated in the beginning. This essentially lets the chef use the robot as a way to investigate different designs, as the robot can be static in its' movements - being the constant, whereas the chef can test different methods or variables.

Fig. 7. On the left: The robot and chef collaborate and experiment with Food Visuals. On the right: The robot works with Modular Cubes from culturally different dished and forms new combinations at the diner's table

Modular Food Cubes. This experiment is tied to the field of architecture. However, the purpose of the experiment is to compose culturally different dishes by a robot using ingredients in cubes. Thereby creating a modular system, and somewhat larger mechanical structure, where the diner's dishes are to be created. The chef creates and prepares the modular ingredients which the robot either systematically (e.g. based on traditional cultural dishes), and randomly, puts together and compose it into a dish at the table.

Fig. 8. On the left - Brownie Wall: Taking inspiration from the field of architecture, the robot builds complex structures from food blocks. On the right - Tension: Tension is built as the robot constructs a structure from food blocks and then destroys it to the surprise of the diner.

Brownie Wall. This experiment, Fig. 8, builds on the field of architecture and how to fabricate complex and modular structures. In this case, the chef prepares the ingredients as modular building blocks for the robot to construct structures for serving. With the precision and accuracy of the robot, the chef will be able to create complex structures with the food thus enhance the food experience of the diners - it can even be built at the table. One could imagine how the robot could continuously build complex structures for each course at a restaurant, letting the diners experience cultural rich food whilst watching the next course being built in front of them.

Tension. This experiment is about building tension and playing on the expectation of the diner to what is going to happen, or likely to happen, in the plating and serving of food. The robot compose a dish and builds it in a seemingly predictable composition. However, as the final details are being made, the entire structure is suddenly contradicted and ruined in a series of rapid and random movements by, the otherwise very precise and reliable, robot. The serving of food is often not tied to meaningful and aesthetic performances as such. The aesthetically pleasing aspect is created, when the chef is plating the dish, but not much change when it is served. Surprises often come down to people not knowing exactly what they are getting or expecting something, but getting something very different.

We want to further play on the serving of a dish and how you can move the expectations of how a dish is composed and served. By letting the robot create a structure that seems to be predictable, to then spoil it at the end, we seek to surprise and impact the dining experience as a whole.

Chaos. Giving complete control to the robot is often tied to the notion of assembly line manufacturing, as the robot is tasked to do same sequence of movements repeatedly. However, in this experiment, we give the robot the control of choosing
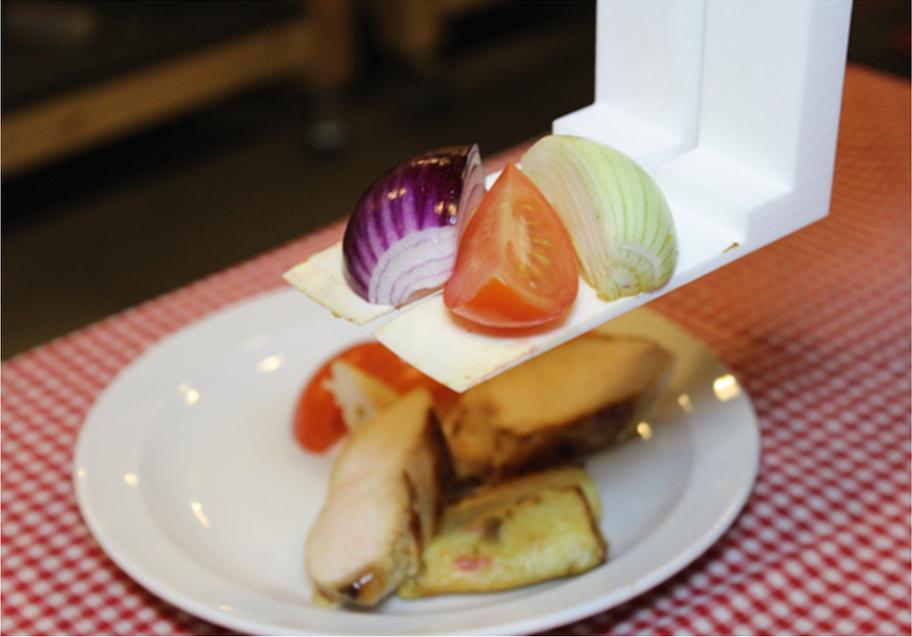
Fig. 9. The experiment of chaos. The robot decides what to be served based on a variety of ingredients

ingredients. It can either be chosen through randomization within boundaries, e.g. choosing one type of meat, two types of vegetables or full randomization, simply choosing arbitrary number of ingredients for a dish. Choice can even be based on external sources, such as atmospheric noise, the sound level in the restaurant etc. By randomizing the choice of ingredients, the control shifts away from the chef, and in some cases even the robot, in order to base the construction of a dish on a non-intentional design approach. This can also be seen as a way to surprise guests, sitting together at the same table and ordering different dishes, which the robot can mix together based on known principles, e.g. beef goes well with root vegetables (Fig. 9).

4.3   Reactions, Feedback and Ideation from Prototypes

The exploratory prototypes were created and documented with video, which was then provided for chefs and serving staff to review. A compiled short video provides an overview of each of the nine design prototypes [29]. A questionnaire accompanied the video and was shared on several public forums for Danish chefs and shared directly with two American chefs with a total of 10 respondents. The cross section of respondents was selected to gather feedback from chefs from the Western European perspective, however, we do not claim for this to be an exhaustive inquiry. Rather, we aimed for initial insights and feedback on

the prototypes so that we could engage in further discussion about the possible future of the kitchen with robotic agents and identify possible refinements as we continue to develop prototypes for our future design work.

The questionnaire was comprised of a still photo of each prototype from the accompanying video. There were 18 questions, two for each prototype, following the form, *"What was most interesting about this prototype, and why?"*, and *"What aspects of the prototype did you dislike, and why?"* Respondents were assured that there are no right or wrong answers and that our aim was to gain feedback based on their opinions, impressions and that we welcomed any and all feedback they wished to share.

We then discussed the videos in contextual interviews with four of the respondents to gain deeper insights and to probe them for additional feedback and ideas. In the interviews, we explored the beliefs and opinions about robots and then looked for scenarios in which the chef seemed to provide contradictory statements. As described in [32] we wanted to uncover "...how the subject is solving problems." We did not seek to confuse or challenge the opinions of the chefs, but rather to explore the mechanics behind their choices and to better understand the conditions in which they accept and embrace robots as a helpful tool as well as when and why they reject them.

The focus of this paper is not to show the most refined prototypes, but to conceptualize the responses and ideas about how future robot-supported food experiences can appeal to the diner and support the creative desires of the chef. We now review the results and insights gained from this process.

5   Emergent Concepts and Ideas

The insights gathered from the design explorations inform our understanding of the design space for aesthetic robot food interaction. Based on the open-ended feedback and interviews in response to the video prototypes, we identify the following key concerns when designing robot-supported interactions with food: issues of control between the human and robot and the perception of robot behaviour.

The chefs were generally supportive of the use of robots - 90 % expressed support for at least some of the prototypes, and 80 % provided key insights about how the individual scenarios can be refined to become more appealing. In the open-ended feedback the chefs expressed an interest in the topic and for more than half of the prototypes. Only one participant provided feedback without specific references to individual prototypes. Some of the respondent chefs did not appreciate our approach in the domain, as they saw it as a direct replacement of him/her even though our proclaimed focus was on collaboration between human and robot - *"Waiters and especially the work of a Chef is craftsmanship - let it stay this way!"*. This resistance to technology was not unexpected, in light of the research that identified a growing trend toward deskilling and attrition due to technology in the food industry [36]. We were delighted, however that most of the chefs opened up and helped to design possible robot experiences for

the future kitchen. Other aspects of the prototypes raised concerns for several respondents, e.g. speed and precision, which we will describe more closely in the following sections of the paper.

5.1 Dimensions of Control

Control of ingredient placement has been a central aspect in the development and reflections about the prototypes. From the initial observations in the kitchens, the creation of a dish requires task planning and management of several concurrent processes. However, in the context of human-robot interaction, the current lack of a common language between chef and robot reduces the possibility of negotiation. This forces the chef to rely on the robot as reliable and an active partner instead of a tool. In addition, in order to achieve collaborative control, the chef has to function as a resource that serves the robot, providing information and processing.

In addition, through the language of action, we see examples of the chef creating boundaries for which the robot can work within, Fig. 6. The chef can either give full control to the robot, essentially letting the robot build the dish according to external sources or a pre-programmed repertoire of e.g. patterns and shapes. Fong et al. [23] suggests considering both human and robot needs when designing HRI systems. By giving the robot control, the needs of the robot are central to how the dish is composed, as the robot has to express its needs regarding e.g. ingredients. The chef has to process these needs and react upon them in order to complete the task at hand. The needs can be expressed in explicit and implicit means of gestures. The implicit gestures are categorized as manipulative gestures [12] where it is the actions and motions of the robot that communicates its intentions and needs. Explicit needs are grouped as communicative gestures [12] where pointing and various types of signs are used. This is seen in contrast to how the robot can act as a fully controllable tool, which the chef can choose to use and control just as any other kitchen tool or utensil. This form of control with gesturing either implicitly or explicitly applies to both chef and robot. We elaborate on why non-verbal communication is ideal to use in next section.

In order to give an overview of our exploratory prototypes and how they correlate to the dimensions of control, we have mapped each of them onto a matrix, see Fig. 10. The dimension of control, from Robot to Human, has been visualized along the x-axis of the diagram. Each of the prototypes has been placed according to how they were conducted, however we envision that the majority can be moved to either side of the axis, if control was negotiated differently.

Through the valuable feedback from the chefs and serving staff, additional ideas and concepts emerge as they add key insights to our exploratory prototypes. Even though some people have difficulties imagining robotic agents in the kitchen regarding some of our prototypes, they still seem capable of envisioning how the robotic agents could improve the kitchen and the processes within. An example thereof, is a chef generally being reluctant to robotic agents in the
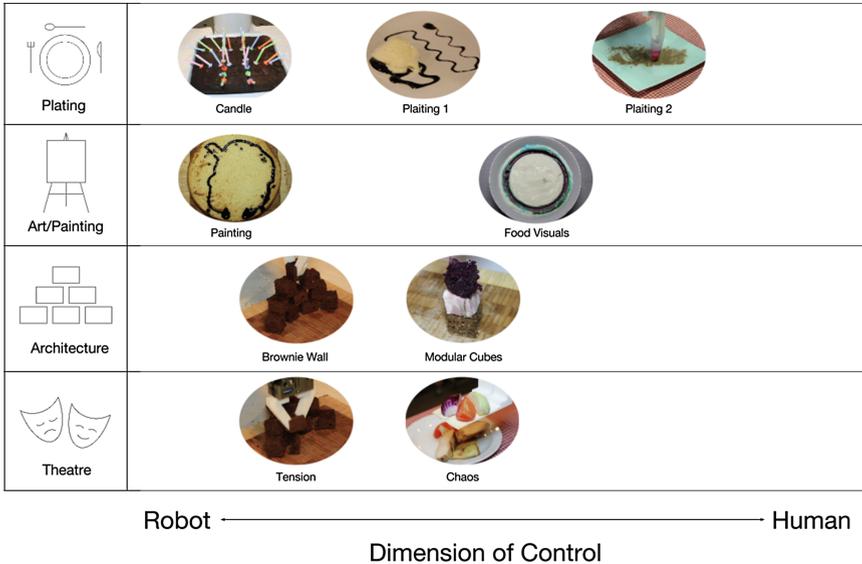
Fig. 10. The experiments mapped to a matrix of categories and dimensions of control

kitchen, who briefly presents an idea to the concept of the "Brownie Wall" prototype. He explains how it would be interesting to introduce the diners with an iPad application in which you build and create structures which the robotic agent in turn converts to actual structures of food by the table in real-time.

In the above example, the role of the chef is the diner along with the control, however, the robot won't acts as a tool in a simple sense, as it becomes an extension of the chef and what the chef/diner is capable of.

5.2   Perception of Robot Behaviour

As a result of our questionnaire, we found that people often perceive robotic movements as either mechanical, i.e. moving one axis at a time in a sequential fashion or more human-like by doing linear movements or moving all axis around a tool-center point - *"It seems artistic in its movements - wavy movements across the plate. But it also resembles a machine when it suddenly stops in the end."* However, as people attribute human-like behaviours to the robotic movements, the robots primary advantages such as speed can have consequences. Thus, seeing a robot complete a task at great speed might resemble that of a person, who does not care for the task-at-hand, thus wants to complete it as fast as possible, regardless of the outcome - *"The robot almost seem as it doesn't wanna do the task. The candles are being placed quick as it just has to be over with..."*. This is seen in contrast to the characteristics of craftsmanship, where the attention to detail is quintessential. In relation to this, much research has already focused on the expressive behaviour of non-humanoid robots and how

non-verbal communication [13, 34] can affect the perceived emotional state of the robot based on the robot's motions [39]. As Saerbeck and Bartneck [39] notes, the varying degree of speed/acceleration can have different affects to the perception of the agent conducting a task from being done "carefully" to "aggressively". This corresponds very well to our initial findings from the previously explained prototypes in this section.

Furthermore, when combining both speed and high precision, the robot draws more focus than the object that it is manipulating - the aesthetic experience become more that of amazement of technology and the inner workings of robots than the plating of a dish. In our exploratory design prototypes we find that the robot can either enter the center stage for an experience or be more of a passive actor or tool in the creation of aesthetic experiences. The dimension of passivity correlates with the dimension of control, as the robot takes more control, it is brought to the forefront and the motion is more that of a theatrical performance.

Additionally, when in a collaborative environment, where non-verbal communication is essential and central, perceiving the robot's motions and being able to infer its' intentions and actions is of great importance. In order to gain joint intention the chef and the robot needs to know the intentions of each other [12]. This should be achieved, according to one of the respondent chefs, by gesturing explicitly through communicative gestures to the robot, when asked how she could envision ways of controlling the robot, she answers: *"I think the easiest way would... kind of.. grab the arm, physically grab the arm.. and place the arm over?"* However, to strengthen the cooperative nature even further, the chef and robot can react on more implicit communication, where the intention of one partner lies within its' actions. By using manipulative gestures [12], verbal communication can be eliminated as it can negatively influence time and efficiency.

Further more, the basic notion of speed and precision is still a key concern as chefs still strive for speed in a kitchen. Tasks have to be finished as quickly as possible. This is a reappearing concern in our online questionnaire, as seen by the responses *"With more speed and precision it could work"* and *"It's too slow, food will be cold before the plate is served"*, which was in relation to the question - *"What aspect of the experiment did you not like?"*. The attributes of the robot used in the exploratory prototypes was seen as both positive, but also negative as speed, sound and the industrial appearance could affect not only the chef's user-experience, but also the diner's experience when the robot is being placed in the forefront of the dining experience.

In addition to this, in modern society, technology is ubiquitous and we tend to forget about it as it becomes more pervasive. The perception of technology is also at the point that if it does not work correctly, it takes our focus; we get irritated and frustrated. We tend to become oblivious to the complexities and intricacies of the technology that controls the robot. During the realization of the experiments, the authors hypothesised that the diner could become fascinated of the robots' accurate and rapid movement, in the same way as designers and architects embrace complexity in their designs as a way of engaging the viewer [11]. From building a curved wall to careful delivery of a dish, the perception of

robots shift in a positive way. In the same way, as a viewer might appreciate a complex structure, he or she could also appreciate seeing how such a powerful, complex robot can be so delicate and precise in a way that surpass human abilities and precision. The appreciation of a robot's movements can be put in the perspective of a theatrical performance as all the robots' axis works both independently and in relation to each other, synchronized and often in a harmonious fashion. The appreciation of complexity is closely tied to how attributes such as sound, speed and precision are perceived by the viewer. The sound of the motors operating within the robot combined with the accelerating and organic motion contributes to the users' experience of the robot.

Consequently, the experiences that unfolds over time are not bounded to the action and task-at-hand of the robot, but can be tied to how it performs these tasks and actions. The diversity of the movements and how it operates while doing an otherwise dull and repetitive task, forms new experiences for the spectator as it differs from the norms. This could be further emphasized by adapting the method of Saerbeck et al. and their use of the PANAS and SAM scales for assessing affect in relation to motion of the robot [39].

6   Discussion

We outline key concerns for aesthetic food interactions supported by robots that we propose can be useful for making sense of the design space and opportunities for exploration with future work. In addition to the design of technology supported experiences, we contribute to an understanding of how people experience food, which has been an activity that has involved tools, ritual and cultural influences well before digital technologies entered the stage. In addition, we broaden the discussion of how we perceive robots as an entity we collaborate and interact with to create an aesthetic food experience. Hence, robots are not merely a tool to obtain efficiency, but can be enriching in a collaborative environment as is the case with the modern kitchen.

6.1   Robots in the Forefront of Food Experiences

The roles of robots are rather firmly rooted in the existing examples of service robots, industrial manufacturing, etc. Placing the robot in forefront of the experience of a diner suggests further scenarios to be explored. As noted earlier, letting the robot perform its' tasks in the view of the diners seems to create varying degrees of aesthetic experiences. People want to explain what is happening and struggle to make sense of its movements. In most cases the chefs explain the behavior of the robot as if it is a human being. This anthropomorphization includes ascribing human-like intention and perceived personalities, which means they tend to treat these types of machines as social entities. Furthermore, the careful movements as a waiter noted, are often explained as being intriguing or mesmerizing. This probes some interesting questions of the robot as a social actor and what role it has along with social skills [19].

Throughout the design explorations, the robot can be positioned in various stages of a dinner experience. The role will then depend on the perspective of the person looking at it. A chef can see it as a partner/companion or a simple machine/tool according to the work of [19], to enhance his own creative process, while the diner can see it as a chef, waiter or even a social agent as part of the actual experience of eating.

In the prototype demonstrating "Tension", Fig. 8, the robot builds a structure, which the diner expects to be completed, only to find that the robot destroys what it had been building, thus sparking feelings of asperity. Why would it destroy something it had spent time building? It suggests that the chef might not be in complete control of the robot causing a sense of apprehension for the diner. In addition to this, the robot takes on a role by itself as a chef or waiter putting itself at the center of the dining experience. The purpose of this is not to destroy dishes and frustrate diners, but merely a way to entertain and surprise diners at the table. In many dishes, we have certain expectations to how it is prepared and presented, this preconception can be challenged directly in front of the diner.

Furthermore, during the "Painting" prototype, viewers might embrace the personal attribution it imposes on the dish. Thus, appreciating the presence of the robot and how it contributes to the social experience. This can be further exemplified in the prototype exploring, "Chaos", where the diners rely on the robot to serve a dish to their likes. It pushes the limits of the dining experience as the norm prescribes that you get what you ordered. However in this example, control is partly given to the robot, as it is the entity to ultimately decide what to serve based on the chef's prepared ingredients from the diner's original order.

Depending on where the robot is placed, we see contradicting statements regarding what role the robot should adopt. One chef noted in general, that the robot should only be used as a tool or extension of the chef, but never replace the chef. However, the particular respondent had no issues with delegating some of the human waiter's tasks to a robot: *"What do you call it.. Saving money on waiters, so they [the robots] become the waiters and the setup… Kind of… Go down and light up candles, give a presentation of the menu, while the [human] waiter is pouring wine."* These contradicting statements illustrates some of the fears that the chefs have regarding the use of robots in the gastronomical world.

6.2   Robots in the Background as an Active Partner for the Chef

As stated earlier in our research problem, we seek to give the robots more substantial roles in the kitchen alongside chefs and serving staff. Fulfilling in a way, where the robot contributes to the creation of culture, not just taking over laborious tasks that are seen as constraints for the chef's creativity, but instead taking part and contributing to this creativity more directly.

When working in conjunction with chefs, the number of design parameters can be increased by using the robot as a fabrication tool. An example of this can be seen in our food coloring prototype, where the robot can stir in complex patterns.

If we further develop this line of thinking, the observed chefs noted robotic agents could be beneficial in repetitive tasks, but did not want to spend much time in instructing the robots. Perhaps for cutting vegetables, a chef could direct the robot to cut in specific motions and patterns, relying on the kinaesthetic experience of interacting with the kitchen tools in their hands to signal and control the robot. This correlates well with the existing praxis of communication through action and hand movements that takes place within the kitchen staff. Instead of supporting existing practises in kitchens, a robot could also seek to alter them, such as the process of designing a dish. An example could be that a robot working within a range of options to plate and continuously change the plating over time as opposed to the more static process of designing and afterwards, replicating. As seen in our observations, the actions of a chef's cooking can also communicate needs to the near surroundings, which causes spontaneous collaboration and assistance between chefs. In a similar fashion, a robot could take a non-intrusive role of an assistant or even operate as an extension of the chef. An example of this could be a Chef plating two of the same dish, whereas the robot would replicate the design of the dish that the Chef is currently plating. The robot and chef could also work in shifts when plating, each placing an ingredient in relation to what has just been placed, such as seen with our plating experiments. By using the ingredients as means for communication, such as the plating with chocolate powder experiment, the communication happens through simple gestures that are contextual and explicit.

By focusing on the robot as a mentor instead of simply a collaborator or assistant, the robot could also take on the role as a scaffolding tool, helping Range chefs learn the specific tasks and routines of a cooking station or simply new plating designs or techniques.

So far we have discussed the robot as being visible and integrated to the experience, however, the robot can be helpful in various other ways. For example, the robot can act as a dynamic jig for the placement of objects. The robot could also be used as a creativity toolkit that helps Chefs explore and develop new plates that they then can do later by hand. There are many ways to imagine robots taking up roles alongside and supporting Chefs and serving staff–our explorations have only begun to open the design space.

7   Conclusion and Future Work

We have, through design explorations, seen examples of how the chef and robot can collaborate to create experiences for diners and even for the chef himself. Using a robot in various methods of cooking can enhance creativity as new possibilities of methods in handling food opens up.

The exploratory prototypes developed in this project have only sketched some of the directions in which a robot and chef can collaborate. The kitchen is one of the most important culturally significant contexts that shapes our everyday lives. Old traditions are taught from parent to child and these traditions move around with us in a globalized world. One can easily catch a glimpse of

other cultures, simply by dining out at one of the many restaurants found in the modern city. In our explorations, we have focused mostly on western food, specifically Scandinavian cuisine, however traditions from other cultures should be investigated and might provide additional insights into how a chef might benefit from working a robotic collaborator. By investigating the food related traditions from other cultures and through engaging with chefs, serving staff, and diners from a wider perspective, we expect to uncover additional and divergent responses towards robotic assistants in the kitchen. This continued exploration into other cultures marks exciting and important directions for future research.

The exploration of control between robot and chef can be further investigated by implementing it into existing processes or by creating entirely new processes. Current processes dictate that the visual expression of dish is static after an ideation phase, which the robot could support by taking and giving control to the chef, forcing her to investigate plating through a more unexpected experimental process. However, we could also imagine that plating was not only limited to the creation of a dish, but instead redesigning the dish continuously each time it was served. As seen in our experiment with randomization, the dishes could also be plated uniquely in front of the diners, creating a more personal experience and possibly greater appreciation for the food and the experience surrounding the consumption of food.

A similar future direction for the dimension of control is to investigate how the level of control correlates to creativity. Relating to Csikszentmihalyi's concept of Flow in positive psychology [18], it would be interesting to explore how the robot could balance and adjust its contributions to maintain the challenges presented to the chef, thus maintaining a state of flow. This and other opportunities made possible by robots working alongside humans signal important work.

Lastly, in relation to the flow of creativity, the language between human and robot is an interesting topic for further investigation. In the "Plating 1", Fig. 5, the chef or robot creates a boundary through manipulation of an ingredient, thus communicating intention through action. We invite exploration into verbal as well as non-verbal communication for these situations of real-time coordination. Cooking involves manipulation of physical ingredients and tools and we hope that our work inspires new experiments into the domain of contextual, gestural/action-oriented communication.

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