Sketching the Future of Human-Food Interaction:

Emerging Directions for Future Practice

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ABSTRACT

There is an increasing interest in food within the Human-Computer Interaction (HCI) field with emerging interactive prototypes that augment, extend, and challenge the various ways in which people engage with food. The emerging subfield is defined as "Human-Food Interaction" (HFI). Given the rapid advancement of interactive technology that converges with a wide range of food settings, this article seeks a continuous scrutiny towards the field to ensure it advances in fruitful directions. In this article, we identify nine emerging themes building on the submissions presented by 19 researchers at an HFI workshop recently held at an international conference. Furthermore, we brought to light three potential design and research directions to inspire HFI futures, and, simultaneously, to build a foundation upon which HFI, gastronomy and food science communities can work together.

Keywords: Food, Interaction Design, Human-Computer Interaction, Human-Food Interaction

1 INTRODUCTION

Food is an essential part of life. From birth to death, we spend hours procuring, preparing, eating, digesting, and thinking of food (Rozin et al., 2003), and innovations in food practices have shaped our life experiences (Ulijaszek et al., 2012). The emergence of digital technology has taken food innovation to new heights, including significant changes to the ways in which foods are produced, prepared, and consumed. The convergence between food and technology, producing novel engagements with food, has become a vital matter of interest in Human-Computer Interaction (HCI) research. Innovations are taking place in digital fabrication (Mizrahi et al., 2016), interactive eating (Mehta et al., 2018), and gustatory augmentation (Narumi et al., 2011), have combined to constitute an emerging subfield within HCI, which has been named "Human-Food Interaction" (HFI) (Altarriba Bertran & Wilde et al., 2019; Choi et al., 2014; Comber et al., 2014; Deng et al., 2021; Khot et al., 2019), denoting the "the interconnection between the self and food"(Choi et al., 2014). Subsequently, the various research has turned HFI into a flourishing area of study. The use of digital technology has underpinned a wide variety of implementations that have enriched food practices across bodily (Khot et al., 2017a), communal (Wang et al., 2020), societal (Barden et al., 2012), environmental (Liu et al., 2018), and planetary aspects (Obrist et al., 2019). At the same time, the heterogeneous nature of this emerging field challenges researchers and practitioners to critically engage with the community (Altarriba Bertran & Wilde et al., 2019). In this context, we call for continuous scrutiny towards the field to ensure it advances in fruitful directions.

While there have been various food research in the area of gastronomy, for example, food studies in relation to the arts (Youssef et al., 2018), the humanities (Hsu et al., 2022; Spence, 2021), the natural sciences (Spence, 2022; Spence & Youssef, 2019), and the social sciences (Koerich & Müller, 2022; Plata et al., 2022). However, HFI and gastronomy have different cultures and practices of scientific enquiry and, so far, the two fields have limited synergy in a substantive way to develop a deep and common understanding of food. In this context, this article attempts to build a foundation upon which HFI, gastronomy and food science communities can work together. To support this collaboration, we examined 19 recent HFI works and identified nine emerging themes and a set of future directions that we hope can inspire food researchers and practitioners to collaborate to create preferable food futures.

2 BACKGROUND

Over the last couple of decades, there has been a notable increase in HFI research, highlighting the exciting possibilities for technology to impact our food practices and experiences (Altarriba Bertran & Wilde et al., 2019). To demonstrate new ways to interact with food, researchers have experimented with emerging technologies such as computational gastronomy (Zoran, 2019), food printing (Khot et al., 2017a; Sun et al., 2015), virtual reality (Arnold et al., 2018), capacitance sensing (Heller, 2021; Wang et al., 2018; Wang et al., 2020), robotics (Mehta et al., 2018), electrical muscle stimulation (Niijima & Ogawa, 2016), acoustic levitation (Vi et al., 2017; Vi et al., 2020), and shape-changing interfaces (Nishihara & Kakehi, 2021; Wang et al., 2017) to illustrate new ways of interacting with food. Also, gastrophysics researchers (Spence, 2017) and multisensory researchers (Spence & Piqueras-Fiszman, 2014; Velasco, 2020; Velasco et al., 2018a; Velasco et al., 2018b) have explored new ways for culinary practitioners and designers to use emerging technology to innovate with food design and enhance the associated dining experiences.

We contend that the "technological solutionism" (Morozov, 2013) found in some of the works we reviewed is only one of many ways in which we can bring together food and technology design. For example, Comber et al. (2012) proposed that HFI needs to pay greater attention to people and the ways in which they engage with food, rather than focusing on the efficiencies and novelties that new technologies offer; the authors also argued that due to the nuanced practices and experiences around food and technology, HFI has been evolving dynamically with the varied perspectives of understanding across transdisciplinary research fields, reflecting the diversity of ways people interact with food. For example, prior works from a range of fields, including anthropology (Holtzman, 2006; Mintz & Bois, 2002), medical sciences (Kendrick, 2008; Scrinis, 2013; Willett & Stampfer, 2013), psychology (Bays, 2017; Connor & Armitage, 2002; Rogers et al., 2016), and sociology

(Schneider, 2018; Warde, 2016), have increasingly utilized food as a research vehicle to understand the beneficial impacts that the integration of food and technology can have on human health (McCurry, 2022), wellbeing (Block et al., 2011), social experiences (Chen et al., 2021), and planetary sustainability (Liu et al., 2018).

This transdisciplinary nature of HFI has motivated researchers in the field to initiate a wide range of articulations of the relationships between food, human, and technology, and of HFI's social and environmental impacts. For example, employing three themes – eat, cook, and grow – Choi et al. (2014) put forward a rich platter of perspectives and a variety of expertise from design, computing, and social studies to find ways to design technology toward engaging, healthy, socially inclusive, and environmentally sustainable food futures. Similarly, Khot et al. (2019) reviewed existing research in HFI and conceptulized a rich design space to guide further exploration. While these prior works represent initial attempts to conceptualize how we might understand and design HFI for a better future, they do not offer a systematically thorough revision of the current state of HFI. This poses a question: how do researchers and practitioners remain up to date with the state of HFI, so that they can continuously engage with and make sense of this emerging field?

In response, Altarriba Bertran & Wilde et al. (2019) developed a literature review tool and a conceptual model of the broad spectrum of HFI disciplines, methodologies, and research agendas. Based upon their examination of the state of HFI research, using a taxonomy they developed from a 260-publication dataset, the authors expressed their concern that the number of HFI research "contributions that fix, speed up, ease, or otherwise make interactions with food more efficient, clearly outweigh those that explore the social, playful, or cultural aspects of food practices." In response to this concern, the authors called for more research that focuses on food practices and cultures "to ensure that advances in technology do not come at the cost of enriched, embodied engagement with and through food" (Altarriba Bertran & Wilde et al., 2019, p. 9). The authors also pointed out that their dataset and analysis of the latest HFI research should be continuously updated, to ensure an ongoing meaning-making process within HFI. Likewise, in their review of existing HFI works, which focused on the use of computational technologies, exploration of human senses, and digital interactions in food experience design, Aguilar et al.'s (2019) concluded that "where everyday new discoveries appear, the challenges to be solved are constant, frequently challenging the researcher" (dos Santos Aguilar & Aguilar, 2019).

Additionally, a variety of HFI workshops, Special Interest Groups (SIGs), and events have made significant contributions to the field's understanding and visions of the future of food (Choi et al., 2009). For example, "Future of Food in the Digital Realm" SIG (Khot et al., 2017b) discussed food printing practices and envisioned a future of digital technology for food fabrication, while other workshops (Ferran Altarriba Bertran et al., 2019; Chisik et al., 2020; Davis et al., 2020; Dolejšová et al., 2020; Vannucci et al., 2018) reimagined future food practices and play that can nourish both people and the planet. Also, a "Manifesto on the interwoven Future of Computing and Food" (Obrist et al., 2018) was developed from work undertaken at an ACM Future of Computing Academy event.

Because of the rapid progression of HFI research and knowledge, the HFI community faces the challenge of maintaining the currency and completeness of its understanding of the state-of-the-art. With this challenge in mind, we concur with the call for an ongoing HFI meaning-making process (Altarriba Bertran & Wilde et al., 2019), and we call for continuous and constant scrutiny of HFI to ensure it advances in fruitful, societally desirable directions, and meanwhile, to look at what comes next. In response to these HFI imperatives, this article examines 19 recent HFI works to provide an update to the HFI community's current understanding of HFI work, and to identify emerging themes that indicate promising future directions for HFI research and inspire practitioners to venture down new paths.

3 METHOD

This article is based on the outcomes of a workshop ("The future of Human-Food Interaction") we conducted at the Association for Computing Machinery CHI Conference on Human Factors in Computing Systems in 2021 (Deng et al., 2021). brought together experts with diverse opinions on the design of the experiential aspects of technology-enabled food engagements and offered a forum in which the research community and a broad range of practitioners could learn from each other. To encourage further HFI community-building, we invited a wide variety of submissions on HFI explorations and received 19 proposals[1] co-authored and submitted by practitioners, researchers, and theorists from several universities, research centers, and industry-based organizations across the world. The submission topics included theory, methods, technology, and applications from a variety of perspectives, including computer science, food science, HCI, psychology, design, multimedia and the digital arts, affective and social computing, data science, cyber-physical systems, machine translation, cognitive science, intelligent engineering, digital health, marketing, and communications. These submissions and the workshop discussions constitute the data that this article analyzes (Table 1). The workshop was conducted via videoconferencing, with the activities divided into two parts. In part one, submission lead authors made PechaKucha presentations of their content, then all workshop participants engaged in open discussion around the topics, ideas and research presented. In part two, breakout groups brainstormed the HFI space, challenges, and concepts, then showcased the outcomes of their activity to the whole workshop. We also discussed the future of HFI with specific attention given to how technology design can contribute to stimulating, sustainable, just, and socio-culturally rich food futures.

[1] All submissions can be found on the workshop's online collaboration platform here: https://miro.com/app/board/o9J_lLLQmP0=/?share_link_id=885890873005.

We analyzed the workshop submissions and the workshop outputs to identify key themes. We followed a reflexive thematic analysis process (Braun & Clarke, 2019), whereby we progressively made sense of the workshop submissions emphasizing our "reflective and thoughtful engagement" with our data and analytic process. While thematic analysis is quite common in HFI research, its procedure is the subject of some debate. (Braun & Clarke, 2021). Instead of rigidly following a traditional "phase-approach" procedure (Braun & Clarke, 2012), we believe that "quality reflexive thematic analysis is not about following procedures 'correctly' (or about 'accurate' and 'reliable' coding, or achieving consensus between coders)" (Braun & Clarke, 2019). First, three authors of this article independently reviewed the workshop submissions to establish an overview of the data and identify patterns of shared meaning (emerging themes) across the works reflecting the primary design/research directions of future HFI. Using this initial list, two of the researchers iteratively combined and synthesized the themes based on their commonalities and differences. After three iterations, nine key themes emerged from the analysis: 1) food perception, 2) blending interfaces, 3) food magic, 4) food play, 5) digital commensality, 6) food tech for all, 7) healthy food choices, 8) sustainability, and 9) empowering R&D. These themes were independently checked and confirmed by a third researcher.

4 THEMES

This section sets out the 19 workshop submissions (WS) and their connections with the nine HFI futures themes (Table 1), then defines each theme and outlines the workshop submissions that exemplify that theme.

Table 1: A summary of workshop submissions, authors, affiliations, and key themes

WS	Submission Title	Author(s)	Affiliation(s)	Theme(s)

1	Differences In Remembered Taste and Smell Sweetness in Food and Beverages Between Sweet-Liker Phenotypes.	Chi Thanh Vi, Rhiannon Armitage, Martin Yeomans	Sussex Ingestive Behaviour Group, School of Psychology, University of Sussex, UK.	**Food perception**
2	Motivating Research Intersecting Visual Analytics and Human-Food Interaction.	Michelle Dowling	School of Computing, Grand Valley State University, USA.	**Food perception**; **Blending interfaces**; **Empowering R&D**
		Timothy L. Stelter	Department of Computer Science, Virginia Tech, USA.	
3	The Future of Food is on the (Capacitive) Table.	Florian Heller	Hasselt University–tUL–Flanders Make, Belgium.	**Blending interfaces**
4	Mind-Gut Computer Interaction: Research Areas and Opportunities.	Khalid Majrashi	Department of Information Technology, Institute of Public Administration, Saudi Arabia.	**Blending interfaces**
		Alexandra L. Uitdenbogerd	School of Science (Computer Science), RMIT University, Australia.	
5	Impossible Food Experiences in Virtual Reality.	Carlos Velasco	Department of Marketing, BI Norwegian Business School, Oslo, Norway.	**Food magic**
		Francisco Barbosa Escobar, Qian Janice Wang	Department of Food Science, Aarhus University, Aarhus, Denmark.	
6	Rendezfood – Interacting with Anthropomorphized Food.	Philip Weber, Thomas Ludwig	Cyber-Physical Systems, University of Siegen, Siegen, Germany.	**Food Magic, Empowering R&D**
7	Gastroludology – Gastronomy Meets Ludology.	Yoram Chisik	Independent researcher.	**Food play**, **Food magic**
8	Socially Situated Human-Food Interaction.	Gijs Huisman	Delft University of Technology, the Netherlands.	**Digital commensality**
		Roelof Anne Jelle De Vries	University of Twente, the Netherlands.	
		Mailin Lemke	Delft University of Technology, The Netherlands.	
		Maurizio Mancini	Sapienza University of Rome, Italy.	
9	Designing To Support the Exchange of Food and Eating Practices Between Remote, Intergenerational Family Members.	Aswati Panicker, Kavya Basu, Chia-Fang Chung	Indiana University Bloomington, USA.	**Digital commensality**
10	Digital Commensality Helps Strangers Connect – A Qualitative Study.	Khawla Alhasan, Chee Siang Ang, Alexandra Covaci	University of Kent, UK.	**Digital commensality**

11	"My Mind Was Telling Me 'Stay in Bed All Day... Only Get Up to Eat'": Opportunities to Design Around Food from Eating Behaviors During the Pandemic.	Mario O. Parra, Jesus Favela	Ensenada Center for Scientific Research and Higher Education, Mexico	**Digital commensality**
		Luis A. Castro	Sonora Institute of Technology (ITSON), Mexico	
12	Investigation Of Human-Food Interaction (HFI) and Food Practices Behaviors in People with Intellectually Disability.	Shijing He	Cisco Systems, Inc., China	**Food tech for all**
13	Food Sharing and IoT in Community Building: The Case of Community Fridges.	Sarah Kiden, Joyce Yee, Angelika Strohmayer	School of Design, Northumbria University, Newcastle upon Tyne, UK.	**Food tech for all**
14	Ambience and Appraisal: Effect of VR and AR Generated Ambience on Consumers' Food Evaluations and Food Choices.	Pennanen Kyösti, Vanhatalo Saara	VTT Technical Research Centre of Finland Ltd, Finland.	**Healthy food choices**
		Raisamo Roope	Tampere University, Finland	
		Sozer Nesli	VTT Technical Research Centre of Finland Ltd, Finland.	
15	Exploring Tradeoffs in The Design Space of Human-Centered Semi-Automated Food Journaling.	Xi Lu	Informatics, University of California Irvine, USA.	**Healthy food choices**
		Sruthi Ramabadran	Cognitive Sciences, University of California Irvine, USA.	
		Edison Thomaz	Electrical and Computer Engineering, University of Texas at Austin, USA.	
		Daniel A. Epstein	Informatics, University of California Irvine, USA.	
16	A Future Vision for Sustainable Human-Food-Interaction.	Philip Engelbutzeder	University of Siegen, Siegen, Germany.	**Sustainability**
17	Envirofy: A Real Time Tool to Support Eco-Friendly Food Purchases Online.	Gözel Shakeri	University of Glasgow, Scotland, UK.	**Sustainability**
		Claire McCallum	University of Northumbria, England, UK.	
18	The Future of Meat: Sentiment Analysis of Food Tweets.	Maija Kāle	Faculty of Computing, University of Latvia, Latvia.	**Sustainability**
		Matīss Rikter	The University of Tokyo, Japan.	
19	Virtual Farmer's Market: Towards Virtualizing and Augmenting Food Testing.	Summer D. Jung	Center for Design Research, Stanford University, USA.	**Empowering R&D**
		Chandrayee Basu	Independent researcher, USA.	

Soh Kim	Center for Design Research, Stanford University, USA.

4.1 Theme 1: Food perception

The food perception theme relates to submissions that focus on understanding the mechanisms associated with how we perceive food in the way we do. The theme encompasses research into the multi-sensory nature of food experiences, and how those multi-sensory experiences can be studied and understood by using interactive technology, and research often draws upon other fields, such as sensory science, psychology, and neuroscience.

With respect to food perception, Vi et al. (WS1) investigated perceptions of the sweetness of foods and drinks among people of different sweet-liking types. Their findings suggested a correspondence between people's sweet-liking phenotypes and their memories of the perceived sweetness of foods and beverages. The authors pointed out that this study could potentially inform future designs of more personalized gustatory and olfactory interfaces. Complementing this work, Dowling and Stelter (WS2) proposed an under-explored area at the intersection between HFI and "Visual Analytics (VA)". The authors aimed to help users to communicate their food and eating experiences across cultures and languages via the interactive visualization of food items in the dataset. Using statistical analytic approaches, Dowling and Stelter's system allowed users to compare similarities amongst food items in terms of taste and mouthfeel attributes.

4.2 Theme 2: Blending interfaces

The blending interfaces theme relates to submissions that focused on interfaces that blend the real and the digital world, and it encompasses the exploration of how to make the edible computational and the computational edible.

With respect to blending interfaces, Heller (WS3) presented a new interaction space for food as an edible, tangible, ephemeral interface, by using muffins as part of the interactive medium that could be detected and identified on a capacitive touchscreen. The system enabled animated food recommendations and opened up new ways to arrange and serve food. Majrashi and Uitdenbogerd (WS4) proposed "Mind-Gut Computer Interaction (MGCI)", whereby human mind-gut activities can be blended with external computing devices. The authors envisioned combining brain activities and human motility, secretion, nutrition delivery, and microbial balance with computation. The authors also presented four potential MGCI research opportunities: using ubiquitous, wearable, or mobile computing tools and systems to detect and record mind-gut activities; developing visualization tools to enhance the understanding of mind-gut communications; providing tailored food intake advice (to optimize mind-gut communications) based on an individual's mind-gut activities data; and evaluating user interfaces and experiences.

4.3 Theme 3: Food magic

The food magic theme relates to submissions that focused on the creation of technology-enabled food experiences that go beyond the real and towards and towards the fantastical by defying the limitations of analog food practices and breaking the laws of physics. Food magic research focuses on allowing users to experience sensory experiences that would be impossible without the mediation of computation.

With respect to food magic, Velasco et al. (WS5) proposed a "reality-impossibility" model to guide future research into and design possibilities for "impossible food experiences" via virtual reality. This model aims to open new opportunities through breaking the laws of physics, and the authors envisioned "fantasy dining scenarios where the questions of where, when, who, and what to eat are all open to experimentation." Weber and Ludwig (WS6) conceptualized another future possibility for a food magic experience:

"Rendezfood". The "Rendezfood" Augmented Reality (AR) application enables diners to interact ("chat") with "anthropomorphized" food in a human-like manner. Also, Chisik (WS7) proposed several possibilities for using multimedia for playful eating augmentations.

4.4 Theme 4: Food play

The "food play" theme is concerned with submissions that focused on playful interactions with/through food, including the study and the design of novel artifacts, systems, and experiences that afford such playful interactions.

Specifically, Chisik (WS7) introduced the notion of "Gastroludology" and argued that exploiting "food affordances and properties" holds an inherent potential for play. The author also provided examples of a growing research interest in harnessing technology to engage and play with food. Examples of this interest include the use of image projection to alter the perceived quantity of food, applying electricity to the tongue to simulate taste sensations and create novel taste and texture experiences, and sharing virtual taste sensations to augment social eating and cooking experiences. Chisik suggested that future playful HFI designs could consider the development of games to engage people with the broader cultural and environmental aspects of food, and the design of food as electronic interface elements in applications and games.

4.5 Theme 5: Digital commensality

The digital commensality theme refers to studies of eating together and the multi-faceted nature of social dining. It encompasses research that explores the social dimension of eating experiences and the design of technologies that intervenes with it.

For example, Huisman et al. (WS8) proposed an HFI approach that "considers food and the act of eating as being socially situated", and "technology as a lens through which to view social eating, and develop artifacts that serve as mediators for social engagements around food.” Panicker et al. (WS9) conducted a study on nuanced forms of long-distance communication and social connectedness in families and this study inspired the future design of systems that support healthy eating conversations by facilitating sharing behaviors among family members. Alhasan et al. (WS10) provided an initial account of how current digital platforms (e.g., AR) can offer an enhanced sense of commensality by facilitating “open-up”, “relaxed”, and “informal” communications while users eat. Parra et al. (WS11) reported on an eating behavior study that was conducted during the Covid-19 pandemic. The study’s aim was to inform the design of future interactive technologies to enrich eating experiences, including improving socialization while eating (e.g., turning solo home cooking into impromptu online social activities) as a way of alleviating negative feelings such as loneliness. The authors proposed the design of a virtual space in which people could gather around food (the food equivalent of “gather.town”) and which could be presented as different types of locations (e.g., virtual restaurants, pubs).

4.6 Theme 6: Food tech for all

The “food tech for all” theme is concerned with submissions that focus on food-related inclusive design. This theme encompasses research into how technology can help to make food practices more inclusive, and how to design food-related technology that is inclusive and accessible.

With respect to food tech for all, He’s (WS12) research statement proposed that future HFI design should aim to improve the wellbeing and quality of life of people with intellectual disabilities by reducing public discrimination and prejudice in food practices. He called for the integration of ethnography with user-centric, inclusive, participatory, and collaborative design, and the consideration of deep engagement, interdisciplinarity, individuality, and practicality when designing technologies for populations with special needs. Taking a different perspective on the same goal of creating food technology for all, Kiden et al. (WS13) investigated how a network of community fridges could use Internet of Things (IoT) technology to support social inclusion in culturally diverse neighborhoods.

4.7 Theme 7: Healthy food choices

The "healthy food choices" theme relates to submissions that focused on the design and use of interactive technology to facilitate healthy eating choices.

With respect to healthy food choices, Kyösti et al. (WS14) reported on two experiments utilizing VR and AR technologies to investigate how multisensory ambience could affect dietary behaviors. The results of these experiments indicated that a "sunny day" and "nature" ambience was more likely to nudge participants toward healthier food choices (i.e., rye nacho and vegetable-based dishes). Experiments like these could inform the future development of technologies and consumer studies that aim to encourage/support healthier food choices. Similarly, Xi et al. (WS15) proposed a "speculative survey" of several concept designs of on-body diet tracers and suggested the use of wearable and intraoral sensors to explore users' acceptance of different self-monitoring technologies for food journaling. The goal of these wearables and sensors would be to give users a better understanding of their eating patterns, thereby helping them to build healthier eating habits and manage their weight.

4.8 Theme 8: Sustainability

The "sustainability" theme relates to submissions that focused on overcoming sustainability challenges associated with food. This theme encompasses research into how technology can support sustainable food lifestyles, as well as how food-technology innovations can be ecologically sound.

Specifically, Kāle and Rikter (WS18) reported on their analysis of food tweets to assess changes in the public mood and attitude toward meat consumption over the past nine years.

This report, according to the authors, could potentially “pave the way for, e.g., alternative proteins as well as vegetarian/vegan diets”. Engelbutzeder (WS16) called for future “sustainable HFI” research that addresses the urge for “a deep change in food systems”, and that highlights the “values, consumption and production practices, as well as politics allowing for deliberation and grassroots mobilization.” Shakeri and McCallum (WS17) argued that educating consumers about the environmental impact of their choices as they shop may be a powerful approach to encouraging eco-friendly food purchases. The authors presented Envirofy: a real-time e-commerce grocery tool (in the form of a browser extension) that allows shoppers to reduce their dietary carbon footprint by delivering “behavioral interventions” when they are making purchase decisions. A pilot test suggested that Envirofy could improve “relevant knowledge, skills and perceived consumer effectiveness across all participants” while reducing the CO_2 in their shopping basket by 14 percent.

4.9 Theme 9: Empowering R&D

The theme “empowering R&D” relates to submissions that focused on the mediums, methods, and processes that facilitate research and development in HFI. This theme encompasses research into technologies and methods that support food sector professionals (e.g., food markets, restaurants, and the hospitality industry) to develop digital alternatives that enrich customer experiences, through more personalized options, and help corporations cope with extreme situations, such as pandemics.

For example, Jung et al. (WS19) presented a study on “human-food-human interaction”, which investigated enabling people to try out and experience the food in a virtualized farmer’s market environment. Their study envisioned future virtual systems to bridge the vocabulary gap between food makers and food eaters. Weber and Ludwig’s “Rendezfood” (WS6), aimed to increase awareness and intensify customer loyalty in the catering industry by creating an emotional connection between the customer and food products, highlighting future technological companions (e.g., AR) that enable augmentation and communication with food in a human-like manner.

5 DISCUSSION: FUTURE DIRECTIONS

HFI research has been predominantly a technology-centric endeavor, according to previous research (Altarriba Bertran & Wilde et al., 2019). Such techno-solutionist (Morozov, 2013) approaches may seem to contradict the goal of HFI research, which aims to emphasize the people and the ways they engage with food (Comber et al., 2014). In response, Alonso (2020) identified future opportunities focusing on the materiality and consumption of food. Furthermore, Velasco et al. (2021) summarized multiple areas for future development around multisensory inquiries, including eating, food attitude, social aspect, and ethical considerations. Our analysis of the work discussed at our workshop with HFI experts highlights a set of design and research directions that approach the human-food-technology interplay through a more diverse and holistic perspective. Furthermore, our themes demonstrated a more heterogeneous nature across various areas. From our critical reflection on the themes that emerged from the workshop, here we share four areas of HFI that might give rise to exciting future advancements in the field.

5.1 Design for experiential augmentations via food's material affordances, integrated mind-gut activities, and multisensory experiences

Our themes (particularly food perceptions, blending interfaces, and magic food) revealed that designing for experiential augmentations is an exciting direction in which the HFI field can advance. While previous work has explored technologies for augmented eating, such as eating with mixed reality (Narumi et al., 2011) and digital taste (Ranasinghe et al., 2016), we identified a set of new approaches to designing experiential augmentations. For example, rather than focusing on technological novelty and efficiency, we propose the employment of food and its affordances as a material and playground for interaction design. This direction requires us to consider the food physics (i.e., the physical properties of food materials) (Figura & Teixeira, 2007) and food's aesthetic, affective, sensual, and sociocultural qualities (e.g., (Deng et al., 2022; Obrist et al., 2014; Obrist et al., 2019)). We hope that this focus will reveal new ways to produce, serve, and engage with food. Another approach to experiential augmentation is integrating mind-gut activities within computational systems. Another approach to designing for experiential augmentations is to integrate mind-gut activities within computational systems. One possible design direction could be to consider the human gastrointestinal tract and the brain activities as synergistic parts of the computational systems, with the objective of enabling a more personal communication between the consumer and the creator and delivering more personalized services and experiences in real-time. Furthermore, incorporating multisensory experiences into food practices and contexts could offer a pathway to experiential augmentations for consumers. In this respect, possible design considerations include multimodal HFI through studying the sensorial phenomenon and developing multimedia devices and VR/AR applications for creating playful and magical food experiences. Overall, this direction could potentially lead the way to future advancements in hospitality, food markets and retail shops by enriching any product line and creating novel food experiences.

5.2 Reinforce commensality and sociocultural bonds for communal responsibility

Sociocultural engagement provides an opportunity to solidify food values and norms and strengthen communal ties (Batat et al., 2019), especially, our themes (particularly food play, digital commensality, and food tech for all) emphasized building up a more accessible, inclusive, and just food community for everyone. The future direction of reinforcing commensality and sociocultural bonds, inspired by our themes, suggests a multifaceted pathway. This could include designing technology-enabled remote eating (e.g., tele-dining installations), technology-mediated environments where diners can eat together (e.g., utilizing virtual and augmented reality), or developing Metaverse food communities that place a virtual layer over the physical world and help people to socialize over food. Our themes also point toward a research direction that incorporates inclusive, justice-focused, and participatory design approaches into technology developments, including the use of IoT and the use of open-source hardware to design more accessible food technology. This future direction for HFI design and research could inspire policy makers, social designers, and scientists to build a more engaging, just, and ethical community around food.

5.3 Promote better food choices for health and environmental care

Our themes also revealed the potential for HFI to raise awareness and empower design for healthy food choices and environmental care through technological interventions (particularly healthy food choices and sustainability). The themes suggested two future possibilities of designing technology to promote healthy food choices: the first being to facilitate nudging through multisensory design created through VR and AR; and the second being the use of bodily monitoring devices and on-body sensors to better understand users' eating patterns. Our themes also highlighted possible technology interventions (e.g., utilizing social media to collect food-related data, and developing applications to track customers' behavior in relation to food practices) for improving food attitudes, food beliefs, and food knowledge. The insights gained from these interventions can then guide researchers in their design of novel systems that aim to vary people's food choices and support a more sustainable food future. Overall, we hope that this direction in HFI research and design will light the way for governments and food institutes who are looking for new ways to improve customers' understanding and awareness of their consumption and its impacts.

6 LIMITATIONS & FUTURE WORK

While we acknowledge the limitations of our work, these limitations also present opportunities for future work. We acknowledge that this article does not provide an *ultimate guide* to future HFI research, given that it is based upon the results of an examination of a limited number of submissions made at a single workshop. Our more modest goal is to offer a timely summary of what a group of HFI experts see as the future ways in which research and design might bring food, humans, and technology together to beneficially shape human food practices. The addition of the work and perspectives of other experts would allow for a more comprehensive understanding of the present state of HFI and provide richer insights into future HFI practices. We also acknowledge that HFI does not yet adequately cover some contemporary developments in food studies, including emerging research around: food provenance, authenticity and the use of blockchain (Cao et al., 2021; Foth, 2017; Teli et al., 2022); food waste (Berns et al., 2021; Farr-Wharton et al., 2014; Farr-Wharton et al., 2012); and green energy in food preparation (Kuznetsov et al., 2022). Also, it is necessarily to point out that our work is only a starting point and does not comprehensively address all aspects of contemporary food issues raised in previous studies, including agriculture and production challenges (Pawlak & Kołodziejczak, 2020), food policy and allocation issues (Alkaabneh et al., 2021), as well as hunger (Collier, 2008) and the climate crises (Downing et al., 1996). Our work provides only a starting point that needs to be developed and critiqued further by other scholars and practitioners across food, gastronomy, and HCI. With these gaps in mind, we intend to conduct future workshops, special interest groups, and seminars to continue the discussion of possible HFI futures, and to, thereby, facilitate an ongoing sense-making process (Altarriba Bertran & Wilde et al., 2019).

Finally, we acknowledge that our article originated from a group of researchers who are predominantly from institutions around the developed world (mostly the USA and Europe). Consequently, our results might be perceived as reflecting the biases inherent to our "privileged" positions. For example, the future directions we identify might only be relevant to or in reach of those in similarly privileged positions. Furthermore, as contributors to, and convenors, coordinators, examiners, analysts, and communicators of the workshop content, processes and results, our inherent values, and our beliefs about the HFI field might have biased the selection and characterization of themes and future directions. Nevertheless, we believe that this article's assessment provides a comprehensive foundation for future research that advances the HFI field. Our different roles in the workshop allowed us to develop an intimate knowledge of the submissions and an overarching view of the workshop outcomes as they unfolded. We believe this privileged position helped us to establish and communicate a deep and rich understanding of the emerging themes and future directions of HFI.

7 CONCLUSION

In conclusion, as the HFI field rapidly progresses and expands, overviews of its status can quickly become outdated. Contributions to knowledge and systems in the field also need to be constantly re-assessed with reference to what will no doubt be rapid changes in the field's aims. In this context, we convened a workshop in which we received and examined 19 works by HFI experts. By analyzing these expert submissions along with the results of the workshop, we identified nine themes relating to the objectives of HFI research and design and three emerging future directions for HFI research and design. Ultimately, with our work, we hope to update the current understanding of HFI and inspire researchers and practitioners to venture down new paths.

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