Logic Bonbon: Exploring Food as Computational Artifact

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ABSTRACT

In recognition of food's significant experiential pleasures, culinary practitioners and designers are increasingly exploring novel combinations of computing technologies and food. However, despite much creative endeavors, proposals and prototypes have so far largely maintained a traditional divide, treating food and technology as separate entities. In contrast, we present a "Research through Design" exploration of the notion of food as computational artifact: wherein food itself is the material of computation. We describe the Logic Bonbon, a dessert that can hydrodynamically regulate its flavor via a fluidic logic system. Through a study of experiencing the Logic Bonbon and reflection on our design practice, we offer a provisional account of how food as computational artifact can mediate new interactions through a novel approach to food-computation integration, that promotes an enriched future of Human-Food Interaction.

CCS CONCEPTS

• **Human-centered computing**; • **Interaction design**;

KEYWORDS

Human-Food Interaction, Food Design, Edible Fluidics

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1 INTRODUCTION

Innovations in dietary practices have shaped human evolution [79]. The emergence of computing technology has taken food innovation to extremes, including significant changes to the ways in which foods are produced and prepared, along with the novelty of foodstuffs themselves [79]. Human-Food Interaction (HFI) [21, 22, 42, 70], a recently emerged subfield of HCI, explores the convergence between food and technology and novel engagements with food, including – 3D food printing [31, 48, 53, 99], eating with extended reality [19, 58], ingestible sensors [47], robotics for playful eating [51], digital taste [52, 63], acoustic levitation for food transportation [85, 86], and real-time gustatory manipulation via machine learning [57]. However, to date, most HFI approaches have emphasized the positioning of technology "around" existing foodstuffs, rather than considering food itself to be the "material concern" [95]. For example, electronics (e.g., sensors and speakers) have been embedded into tableware and cutlery [63, 84], wearables such as helmet-mounted displays have augmented eating [19, 57, 58], and screens and visual projections have been integrated into dining experiences [44, 76]. Such technology-driven approaches focus more on the digital devices involved, and less on food's experiential affordances. This is evident by the fact that these systems typically "work" without the food, and the diners do not even need to consume the food to have a digital experience. It is not unreasonable to claim that many of these approaches, while they are technically novel and well-executed, fail to fully realize the potential to use technology to "celebrate the pleasurable and enjoyable experiences that people have with food" [32].

Within HCI more generally, an increasingly common theme is the blurring of boundaries between the digital and the physical [38, 45, 97]. From the emergence of "interfacial" materials (i.e. employing computing technologies to control material or physical manifestations of digital fabrications) [18] to tangible bits [80], interaction design has become a "material concern" [81, 82, 95], seeking to "weave together" the digital and physical worlds [94]. Wiberg et al. [96] suggested that the material understanding offers a "huge" potential to advance HCI by enabling new user experiences. In this vein, our goal is to understand "material integrations" through the design of "food as computational artifact". We seek to explore designs in which food, as a material, is the medium by which computation is realized: the resulting "food items" are thereby computational artifacts. Also, computation means a process that involves any type of "calculation that includes both arithmetical and non-arithmetical steps" [14] that follows "precise rules" [35], no matter whether "it (computation) is implemented through silicon, neurons, or clockwork" [36]. Our starting point is the observation that people often use food analogies in non-expert presentations of computational concepts. For example, our daily food processing can be equivalent to computational processes. The processes lead to changes in state of food (e.g., colors, shapes, flavors) that can

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occur by controlling a data set (e.g., ingredients, condiments) based on an algorithm (e.g., a recipe) and external inputs (e.g., heating, blending). We are reminded of computation – whenever a set of conditions is met, a transition toward a new state begins.

Moving beyond this food-computation analogy raises a question of: *What does it mean for a food to have computational qualities, and how can we design foods that are computational artifacts*?

In this paper, we took our departure from an integration of food and the basic form of computation: the logic gates. The outcome of our "Research through Design [101]" study, is the "Logic Bonbon": a liquid-centered dessert that performs computations via an integrated fluid-induced logic gate system. The Logic Bonbon is capable of computationally regulating its flavor in response to diner inputs. Our work constitutes an initial exploration of what it means to design food as computational artifact. As a result of reflecting on our design process, and an empirical study of diners' experiences of the Logic Bonbon, we propose a provisional set of considerations for designing HFI with food as computational artifact. Our contributions are therefore four-fold: (i) an original design contribution in the form of the "Logic Bonbon"; (ii) a proposed categorization of food-computation integration; (iii) a novel "material integration" approach to designing food as computational artifact; and (iv) four considerations for designing HFI with food as computational artifact.

2 RELATED WORK

HFI has explored a wide range of relationships between food and computing technology. For example, Altarriba Bertran et al. presented a systematic mapping study of HFI research through developing a three-lens taxonomy characterizing the "focus", agency" and "domain" of prior HFI works [11]; Choi et al. brought together a variety of expertise including design, computing and social studies in HFI systems from quotidian practices of eating, cooking, and growing [20]; Also, Aguilar et al. reviewed existing HFI works focusing on the use of computational technologies, exploration of human senses, and digital interactions in food experience design [23].

Our concerns are more concentrated on "material integrations" of food and computation rather than the setting or applications. Finding an analogy in the historical development of computing technology, we propose a new categorization of food-computation integration. The development of computing can be broadly characterized in terms of four generations of computational artifacts. The first generation of computers were external representations that aided human computation (e.g., the abacus and slide rule [74]). The second generation were fixed program computers (e.g., the first digital computer, the Atanasoff–Berry computer [7]). The third generation were stored-program computers for which program instructions stored in memory can be executed (e.g., the Manchester Baby [46] ran one of the first stored programs in 1948). Finally, the fourth and most recent generation of computers is arguably the cyber-physical system: a complex array of adaptive sensors, algorithms and actuators [61]. Following this analogous generational development, we propose four degrees of food-computation integration as follows:

- The first degree (D1): Food-computation integration as representation (leaning on the abacus and slide rule);
- The second degree (D2): Food-computation integration as transformation (leaning on the fixed-program computer);
- The third degree (D3): Food-computation integration as reconfiguration (leaning on the stored-program computer);
- The fourth degree (D4): Food-computation integration as adaptation (leaning on the cyber-physical systems).

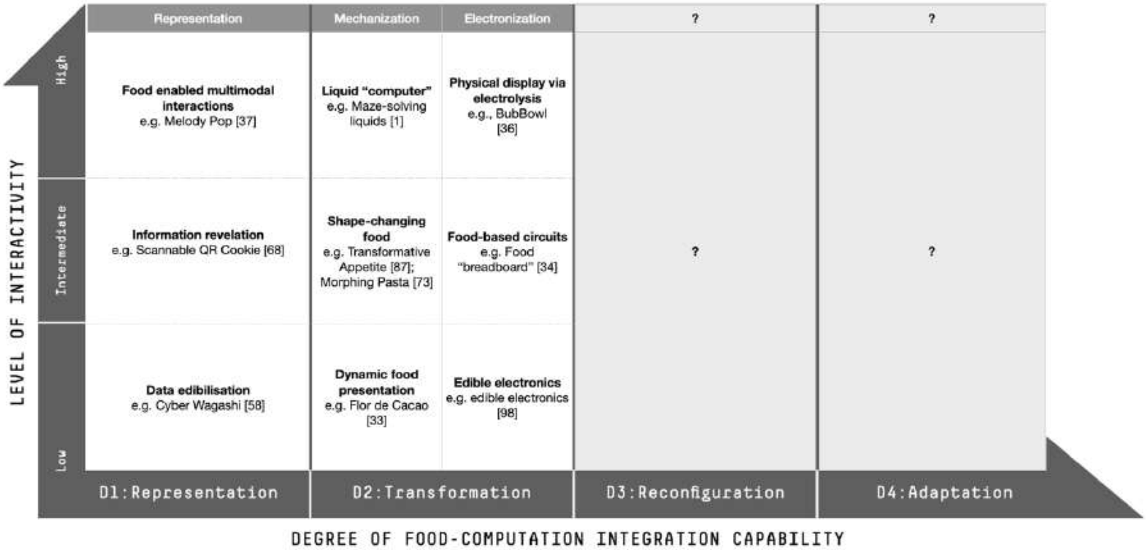
Figure 1 conveys our categorization of food-computation integration. Along the horizontal axis we distinguish the four degrees of food-computation integration capabilities (i.e., D1, D2, D3, D4). In the vertical axis, we distinguish between exemplars of each degree according to three levels of interactivity (i.e., roughly approximating "low", "intermediate", and "high" interactivity). We note here that we do not consider interactivity itself to be fundamental characteristic of food-computation integration. Rather, we use the dimension as a quantitative measure that helps us to distinguish between items qualitatively distinct categories.

2.1 D1: Food-Computation Integration as Representation

Works in the "representation" category have used food as edible representations of data. Wang et al. [90] coined the term "data edibilization" to describe the representation of data with food in order to communicate information "across multisensory channels". With the emergence of digital gastronomy [17, 54, 103, 104], designs that incorporated "printed" data into foodstuffs were enabled through the use of new production processes and parametric design tools [54, 56, 105]. For example, the "Cyber Wagashi" project [60] mapped three weather data features (windspeed, atmospheric pressure and temperature) to the size/shape, height, and color of 3D-printed wagashi (a traditional Japanese confectionery). Although Wang et al. claimed that data edibilization makes food more attractive, enriches the multisensory experience, and has the potential to affect socio-cultural impact [90], it is often unclear how a user should interact with such foods and there is a notable absence of empirical evidence to the contrary. "Information revelation" is an approach to representation in which data is not immediately perceptible, but users can use a tool to reveal it. For example, the QR code on the "QR cookie" [70] can be scanned to reveal a hidden message. When compared to data edibilization approaches, the level of interactivity is higher in this approach to representation, but the locus of computation is in the interaction between the QR code and the scanning device (typically a mobile phone) rather than within the food itself. In contrast, some multimodal approaches shift this locus of computation. For example, the "Melody Pop" [39] is an early example of encoding digital data into food, allowing users to play different tunes while eating their "pop candy". Collectively, these representational approaches demonstrate how "eating" data can be turned into a multimodal (e.g., visual, taste, and auditory) experience [56].

2.2 D2: Food-Computation Integration as Transformation

The static nature of the relationship between food and data in the aforementioned representational category limits opportunities for people to experience dynamic engagement with food. In contrast,



	Representation	Mechanization	Electronization	?	?
High	**Food enabled multimodal interactions** e.g. Melody Pop [37]	**Liquid “computer”** e.g. Maze-solving liquids [1]	**Physical display via electrolysis** e.g., BubBowl [36]		
Intermediate	**Information revelation** e.g. Scannable QR Cookie [68]	**Shape-changing food** e.g. Transformative Appetite [87]; Morphing Pasta [73]	**Food-based circuits** e.g. Food “breadboard” [34]	?	?
Low	**Data edibilisation** e.g. Cyber Wagashi [58]	**Dynamic food presentation** e.g. Flor de Cacao [33]	**Edible electronics** e.g. edible electronics [98]		

Figure 1: The categorization of food-computation integration.

the systems in the “transformation” category are best understood by reference to familiar food-related processes such as cooking (e.g., the rising of a cake). Integrations in the “transformation” category see food as a dynamic form in which the computation informs a change in form, which can then be further distinguished in two approaches: “mechanization”, and “electronization”.

2.2.1 Mechanization. “Mechanization” describes approaches that involve a mechanical form of transformation. For example, pastry chef Jordi Roca created a dessert called “Flor de Cacao” [33] which represents a cocoa bean that opens up like a cacao flower through contact with hot chocolate sauce. The transformation realizes a “dynamic presentation” to engage diners. This mechanical transformation has been extended and materialized as into “shape-changing food”. For example, the “Transformative Appetite” [89] and “Morphing Pasta” [75] projects involve encoding information into food through the fabrication of 2D pasta segments that are revealed as 3D structures through the cooking process. A small number of “mechanization” approaches have realized transformative processes that are more readily recognizable as computations. For example, Adamatzky [3] used liquids (e.g., coffee and milk) with different viscosity to find the least hydrodynamic resistance path in a “liquid computer” to solve shortest-path problems in mazes.

2.2.2 Electronization. The emergence of edible electronics and the ability to fabricate food as functional electronic devices [12, 43] have opened a significant design space for digital interactive food design. With an eye to medical and healthcare applications, Xu et al. developed a number of edible electronic devices including a pH sensor, radio frequency filter, a microphone, and a supercapacitor [98]. However, these works were aimed at addressing medical and healthcare issues rather than diner experiences. Many food items are ionic conductors that can power electric circuits via free moving ions, similar to batteries (e.g., using fruit to light up an LED). Moreover, the inherent conductivity of foods such as breakfast spreads (Vegemite and Marmite) has been leveraged to print viable edible circuits onto “breadboards” [34]. Another example is BubBowl [37], a drinkable display that presents digital information via bubbles using electrolysis. It generates a 10×10 dot matrix pattern for presenting information on the surface of coffee in a cup with which the user can interact: using a spoon to stir the bubbles around, for example.

“Mechanization” and “electronization” approaches use different food properties to realize dynamic transformations. However, we found that most works in this category have barely explored food itself as the material for computation, and fall short of exploiting the opportunities for reconfigurable computation, that is, to realize the third degree of food-computation integrations (D3). With the exception of Adamatzky’s “liquid computer” (which solves a shortest path problem), the transformative character of second-degree designs constitutes only the most limited form of computation (i.e., food was fabricated as only actuators or sensors). Thus, we identify that the space at the boundary between D2 and D3 is likely to be a fruitful site for design.

2.3 D3: Food-Computation Integration as Reconfiguration

Food-computation integration as “reconfiguration” denotes that the food itself is the material that is capable of executing programs the was stored in it. To the best of our knowledge, we do not know of any system within HFI that possesses such a capability, and we contend that food-computation integration as reconfiguration merits further investigation.

2.4 D4: Food-Computation Integration as Adaptation

Adaptive food-computation integrations illustrate the possibilities of utilizing food including crops and microbes to create biocybernetic systems that focus on their automatic operations (i.e., selection, adaptation, self-organization, self-reproduction and autonomy) [41]. Here the "intelligence" of organisms such as plants is used to sense an environment, and make decisions to regenerate, actuate or grow in response to external stimuli [5, 67, 68]. Although "adaptation" is another underexplored category in the HFI literature, we see initial steps towards were taken in prior conceptual works including the "Cyborg Botany" project [67] which envisioned a future in which interactive functions can be grown, injected or placed in conjunction with a plant's biological systems. Similarly, Adamatzky et al. [5] used basil roots as morphological computing devices to imitate the exploration of planets and to analyze transport networks scenarios on the Moon [6]. Furthermore, the "post-anthropocentrist" designs [49] such as exhibited in the "Living Food" project [27], proposed a series of futuristic meals that behave like living creatures, to facilitate speculation on a future in which food can interact with and create hyper-sensations in our mouths.

3 METHOD: RESEARCH THROUGH DESIGN OF FOOD-COMPUTATION INTEGRATION

Our proposed categorization of food-computation integration, in Section 2, yields two major insights. Firstly, most previous work can be categorized within the first and second degree (D1 and D2). Secondly, previous research on food-computation integration has fallen short of exploring food-computation integration as reconfiguration (D3) and adaptation (D4). Consequently, we believe that there exists a gap in knowledge of how to design for such opportunities. In particular, with this paper, we are primarily aiming to contribute to filling the gap identified in D3 by answering the research question: how do we design food-computation integration as reconfiguration? To address this question, we explore the design of a food as computational artifact – the "Logic Bonbon", through a Research through Design (RtD) approach.

We engaged in a RtD process [101, 102] whereby the design of novel interactive food, as a reflective practice, is a source of new knowledge that is "topical, procedural, pragmatic and conceptual" [30]. A key requirement of our RtD process was to ensure that our design activity was "purposeful", that is, that we were designing in relation to a set of authentic goals and constraints. In setting these goals and constraints, we scoped our research, and therefore maximized the likelihood of generating knowledge about, and insight into the phenomena we seek to investigate – in this, the nature of food-computation integration. Our goals and constraints constitute what is traditionally considered to be the design brief, and in our case, this has four principal elements:

- Research agenda: **Reconfigurability**. In this paper, we aim to take a first step in pushing the boundary towards exploration of the nature of reconfigurable food-computation integrations.
- Evaluative frame: **More than edible**. To avoid the pitfall of designing technology-driven "edible" interactions that often neglects the aesthetic, sensory and social qualities of food, when exploring "food as computational artefact" we have also prioritized its palatability and the experiential pleasure to be gained from it, rather than using adequately "edible" materials for housing computation.
- Material constraint: **Fluidics**. In this paper, we explored the fluid-induced logic functions in our design practice to realize food-computation integration, because fluids not only play a key role as a material where computation takes place that bypasses "electronization" [3, 4, 15, 26, 29, 100], but fluids such as soups, liquor, and syrup are also essential elements relishing our dishes.
- Design goal: **Real-time tailoring of food experiences**. Our design goal was to use food-computation integration in our food design in a way which supports real-time modification of the food properties ("reconfiguration") and facilitates individually tailored eating experiences.

4 LOGIC BONBON: FOOD AS COMPUTATIONAL ARTIFACT

We present our design of Logic Bonbon as the first prototype investigating food-computation integration with food as a computational artifact. We see the Logic Bonbon not as a final product, but rather as a material speculation [25, 88], within the RtD tradition, with the intention of creating novel food-computation integrations and enriching the future of HFIs. The Logic Bonbon is a liquid-centered dessert that can perform computation in the form of logic operations induced the dynamics of edible fluids. The Logic Bonbon is designed and fabricated to hydrodynamically control the logic operations of AND, OR, or XOR under a given flow condition, which is triggered by the diners.

Our goal is for the Logic Bonbon to support the real-time tailoring of food experiences. While computing has revolutionized how we process and interact with food, it cannot yet be applied to modify physical "information" (i.e., the appearance and taste of the Logic Bonbon), just at the same rate it receives information (i.e., inputs). By empowering the diners to change the dessert's taste and visual presentation, we hope that the Logic Bonbon can enrich their sensory perception and aesthetic appreciation, building on the fact that taste and vision are key sensory modalities that contribute to pleasant food experiences [69, 72]. Enabling diners to change the taste and color of the dessert has the additional benefit of allowing them to modify and manipulate their dish, according to their preferences just before they eat.

4.1 An Inspiration from Unconventional Computation: Fluidics

Computers have historically taken solid forms – using gears [1] initially, then vacuum tubes [2], and now circuit boards – but computers do not necessarily need to be solid. Fluids can also perform computation [3]. This fact has inspired us to make an edible computational artifact by exploiting fluidic systems. Researchers have been exploiting fluids to embed computation directly into material substrates [4, 15, 26, 29, 100]. For example there is an analogue computer that uses hydraulic components to simulate dynamic systems of the economy [13]. Similarly, Mor et al. [55] developed multiple analogue fluidic sensors at a micro-scale that enabled a set

Figure 2: A photograph of the process of making Logic Bonbons.

of primitive venous structures to function as a responsive display of information. Alongside these analogue fluidic computers, El-Atab et al. [26] integrated computational logic into a pressure-driven 3D microfluidic chip. Prior work has also extended such fluidic logic to incorporate more complex computational processes to control soft robots [29, 92].

In its most basic form, a digital computer is a collection of on (1) and off (0) circuits that are transformed via logic gates Interestingly, various fluidic devices have been developed to accomplish these transformations, ranging from standard binary logic operations (e.g., AND, OR and XOR) [64], to more complex functions like buffer, latch, flip-flop, and even microprocessor [10, 24, 28]. Prior works have shown that analogies that exist between fluidic flow and electrical flow. The fluidic circuit behaves much like the electrons in an electrical circuit [100]. Following this understanding, we have attempted to design a dish where the computation is conducted via fluid-induced logic functions.

4.2 Designing the Logic Bonbon as A Computational Artifact

We conceived the idea of the "Logic Bonbon" after noting that some desserts contain a multi-flavored center, such as traditional bonbons containing a liquor or syrup center that can enrich the flavor experience. We intended to create a Logic Bonbon that is capable of computationally configuring its properties (here, flavor and color) by executing logic operations via integrated fluidic mechanisms in response to external diner inputs. In the rest of this section, we present the Logic Bonbon through its design modularity and multi-layered structure.

4.2.1 Modularity. The modularity of the Logic Bonbon system is a design feature that subdivides the system into smaller parts that can be independently created. They can also be exchanged with modules from different systems. Each basic unit of a Logic Bonbon system consists of a set of an input modules, a logic gate, and an output module (Figure 3).

The non-edible input module consists of a 3D-printed mount (that functions as a plate for serving the Logic Bonbon and transferring fluids into it), two fluid reservoirs in the form of two pipettes that connect with two fluid transfer tubing, and two L-shaped joints. Additionally, two fluid recyclers (as containers) were connected with the opposite side of the mount to recycle a possible fluid waste. These parts of the Logic Bonbon system are not edible, only the edible Logic Bonbon (placed on the mount) consists of a logic gate and output module with a multi-layered structure, which is explained next.

4.2.2 Multi-Layered Structure of Logic Bonbon. Inspired by microfluidic chips which have a planar or sandwiched construction [100], the Logic Bonbon is designed in a form that consists of different layers, each with specific fluidic configurations and logic functions. A Logic Bonbon can perform either an AND, an OR, or an XOR logic operation. We discuss the schematic structure of a Logic Bonbon that can perform an AND function as an example (Figure 4). The OR and XOR Logic Bonbons are designed accordingly.

The bottom side of the "base connector layer" connects to the mount, and the top side connects to the "logic gate layer". The logic gate layer plays a key role in enabling computation. On top of this layer sits another connector layer that connects to two "chamber layers" (one with an overflow vent) that will be filled with fluid and hence function as a display, indicating that the computation was successful. If the two chamber layers reach full capacity, any extra fluids will escape via the "overflow vent". The translucent "window layer" sits at the top and offers the diners a view of the chamber layers so that they can see if the computation was successful, suggesting the Logic Bonbon is ready to eat.

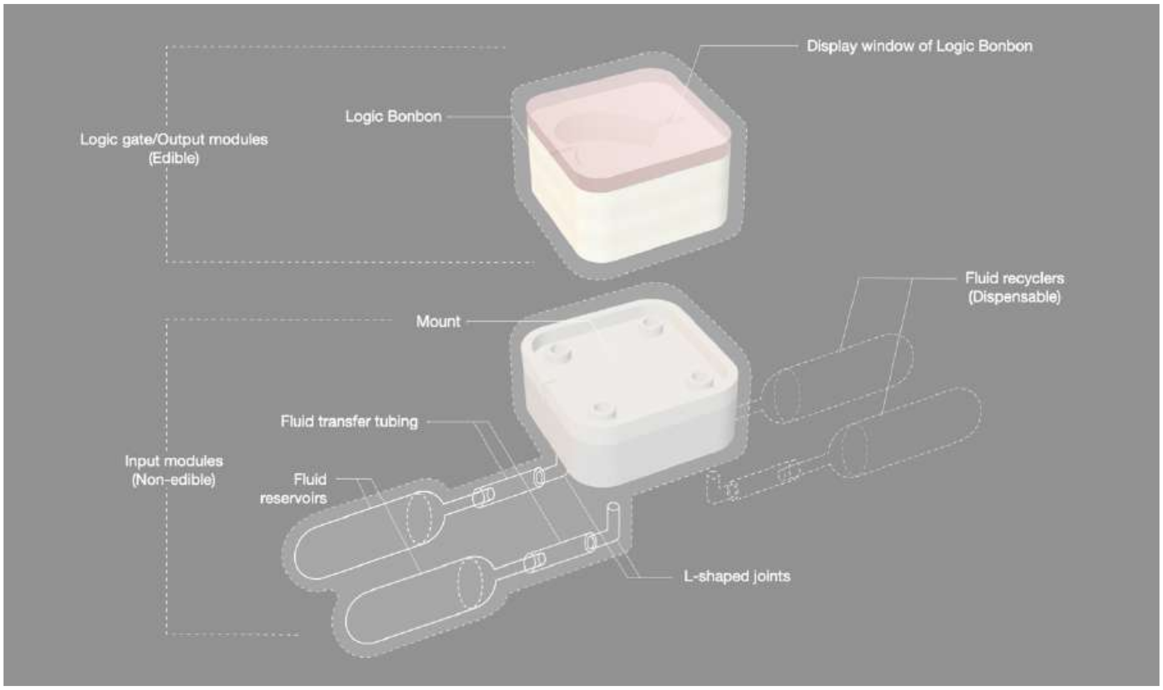


Figure 3: A schematic structure of a basic unit of the Logic Bonbon system.

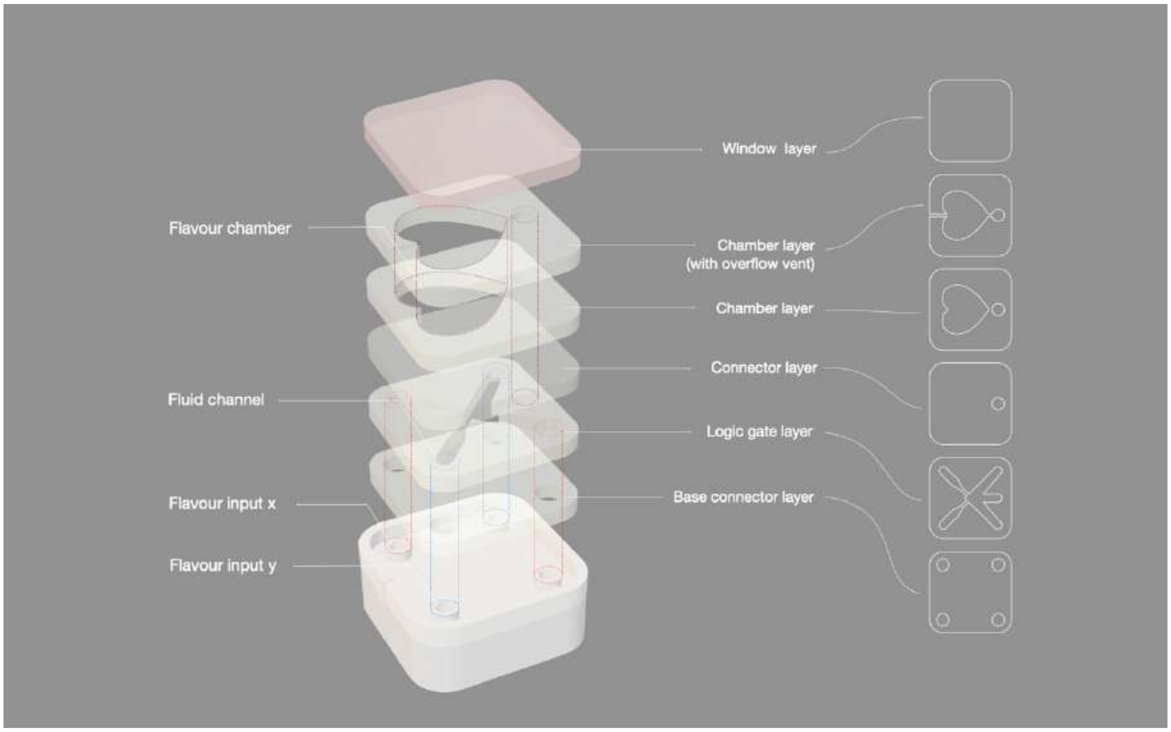


Figure 4: A multi-layered structure of a Logic Bonbon with an AND function.

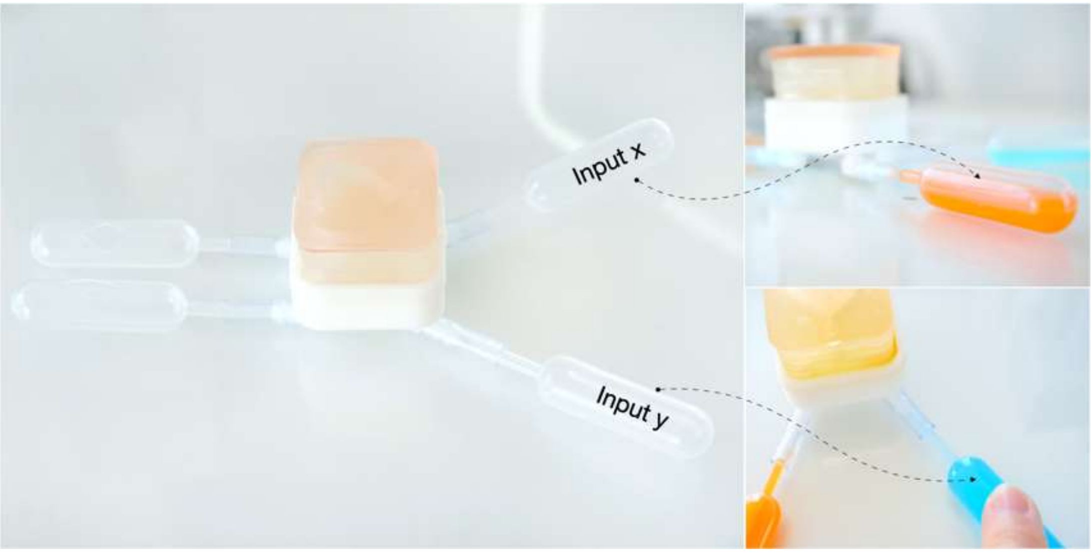


Figure 5: Experiment with a Logic Bonbon system.

4.3 Interacting with the Logic Bonbon

The Logic Bonbon interaction begins with the diners applying force to the flavor reservoirs. The flavor reservoirs are pipettes filled with different flavors. Figure 5 shows an example of a whole Logic Bonbon system with two flavor inputs: "x" and "y".

The design allows the two flavored liquids (inputs) to flow from the pipettes and pass through the plate into the Logic Bonbon (Figure 6). We demonstrates three logic operations and the possible flavor outcomes within a Logic Bonbon: AND, OR, and XOR (Figure 7): each of the Logic Bonbon has been assigned to a different icon which has been printed with the chamber layers for distinguishing the three logic gates (AND gate = "heart", OR gate = "duck", XOR gate = "I"). In addition to the flavor of the Logic Bonbon itself, its logic function produces four possible flavor outcomes when using two flavor inputs: no flavor in the center, flavor x, flavor y, or mixed flavor (Figure 7).

4.4 Design of Logic Gates via Fluidic Mechanisms

One of the crucial features of the Logic Bonbon is the performance of logic functions using fluidic mechanisms. The logic gate layers realize this feature through particular fluidic configurations, wherein the logic functions are implemented using the fluid mechanisms called "beam deflection" [64], whereby fluid flows can be deflected through the interactions with another flow [10, 64]. Figure 8 summarizes three basic fluidic devices (AND, OR, and XOR) and the functions they perform along with their typical configurations and truth tables from prior work on fluidic devices [64]. However, according to prior research, the typical configurations of fluidic logic gates were conceived to "illustrate the functions" rather than "represent actual designs for achieving flow mechanisms" in the real world [64].

Based on this understanding of logic device functions, we explored various options prototyping the fluidic logic gates in order to achieve actual designs (Figure 9). For simplicity, we started with non-edible material. Various configurations of logic gates were designed and fabricated out of acrylics by laser cutting (Figure 10). The logic gates were tested through manual operations using syringes. Figure 11 shows an example of testing an AND gate. The findings suggested: (i) the logic functions are highly dependent on the size and geometries of the fluidic channel; and (ii) the amount of pressure applied to the inputs critically influences the logic operation outcomes.

Prior work suggested that small geometrical changes can be employed in actual fluidic devices to ensure proper operation [64]. Our design exploration found that we could achieve multiple logic functions by simply changing the output and vent ports. For example, an XOR gate can be made by simply switching the vent(s) and out ports by utilizing the AND configuration. This means that the XOR logic layer can be made from an AND logic layer, but the out ports need to be reconfigured: namely, the vent ports become two output ports (Ox and Oy), and the original out port becomes one vent (Figure 12). Figure 12 shows the actual configurations of three common fluidic logic gates we designed along with the correlated fluid flow with the Logic Bonbon.

4.5 Fabrication

We explored four materials (recipes) that are commonly used for desserts: agar jelly, fruit gummy, chocolate ganache, and royal icing. The material selection criteria were: (i) the recipes are easy to prepare. The ingredients are easy to find in everyday supermarkets, and they only require a small number of tools and appliances; (ii) the recipes have been generally acknowledged to be tasty; (iii) the working surface of the material is non-absorbent and durable enough to retain liquid fillings; and (iv) the consistency of the materials is suitable for construction and shaping.

Also, two fabrication techniques were investigated: 3D-food printing and molding (Figure 13). The results suggest that 3D food

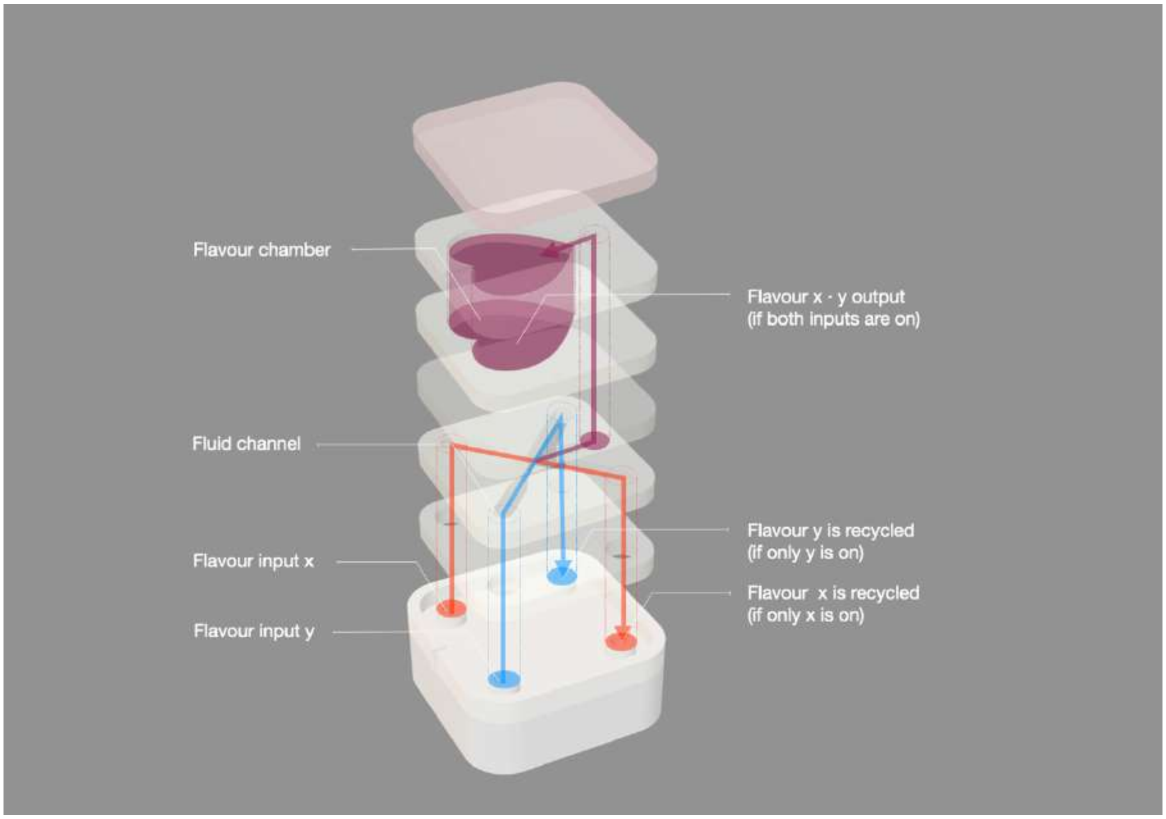


Figure 6: Logic operations of an AND gate.

printing has the advantage that preparation is a simple procedure, i.e., there is no need for additional tools. However, 3D food printing resulted in a somewhat lower resolution when compared with the 3D rendering in the software, which hindered the correct execution of the fluidic logic functions.

To overcome this problem, we used laser cutting molds to fabricate different layers of the Logic Bonbon. This process allowed for a higher resolution, and the fluidic logic functions performed more effectively. However, not all materials were suited for all fabrication techniques. We found that chocolate ganache and royal icing are well-suited for 3D printing but not molding. On the other hand, agar jelly and fruit gummy are well-suited to molding. As the molding resulted in a higher resolution, and consequently worked better for the fluidic logic functions in our testing, we decided to create the Logic Bonbons using agar jelly and fruit gummy (Figure 13).

5 EXPERIENCING THE LOGIC BONBON

This study aimed at utilizing the Logic Bonbon as a research vehicle to investigate how diners eat, sense and talk about food as computational artifact in an everyday context (i.e., participants' homes) that leads to broader empirical insights for future design.

5 dyads of participants from five households (10 participants) were recruited via advertisement and word of mouth. The age of participants ranged from 26-33 years, (M=29.9, SD=2.3) with 6 participants that identified themselves as female and 4 as male (no non-binary). There were 4 romantic relationship dyads and 1 friendship dyad. Participants were designated by number, from P1 to P10 (P for the participants). At the beginning of the study, participants were asked to rate themselves to what extent they consider themselves as a "foodie" and "computer guru", respectively, on a scale of 1 (not much) to 10 (very much). This provided us with first-person insights into how they perceive themselves as a person who has an ardent or refined interest in food, and at the same time, as an expert on computing. This (albeit fuzzy) self-rating might be useful to put their insights collected through the interviews into the context of our focus of research: food and computing (Table 1).

5.1 Deployment

Each participant was assigned a ready-to-make kit of the Logic Bonbon system, which included a set of unassembled layers of the Logic Bonbon (with three logic gates), a set of pre-made Logic Bonbons without fillings (with one AND gate, one OR gate, and one XOR gate), and two sets of connection components. Each dyad also received different beverages with different tastes and colors (incl., juice, soy milk, and black coffee).

5.2 Procedure

Each participant was given instruction on the preparation and assembly of a Logic Bonbon system, and they were asked to conduct two activities. First, participants were asked to assemble a single

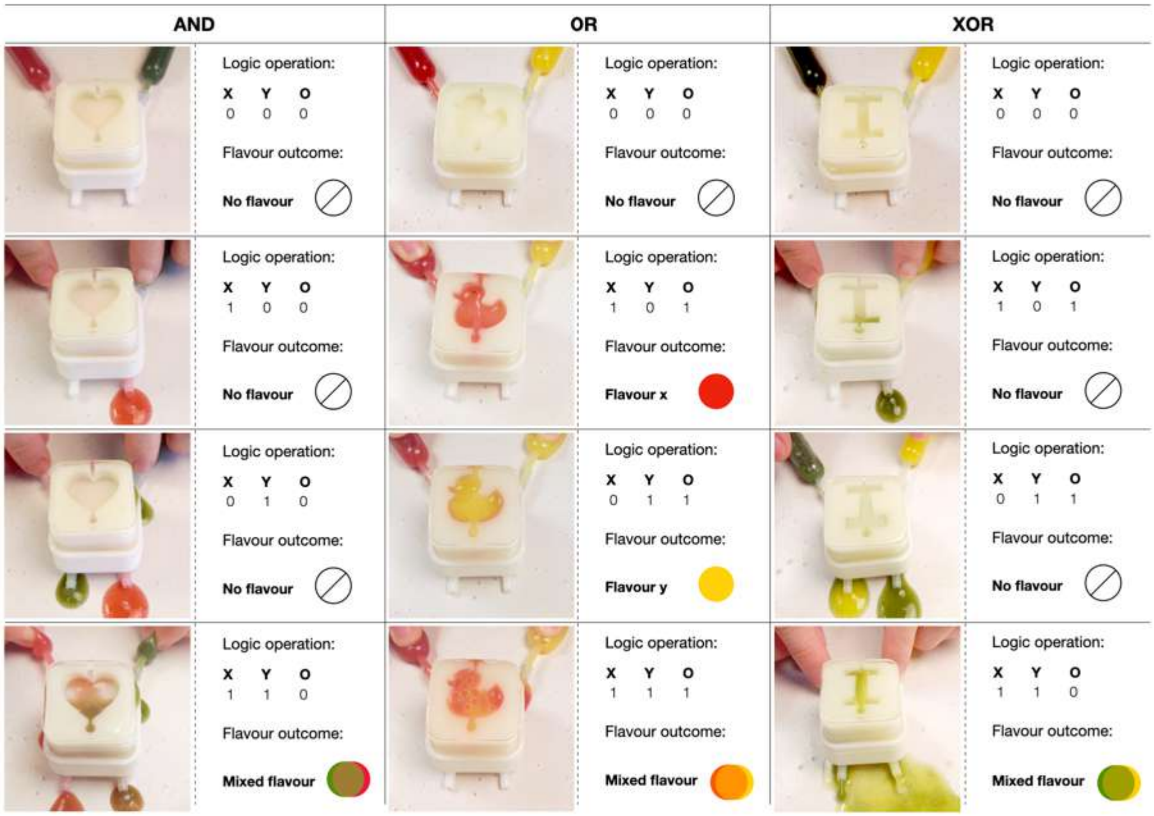


Figure 7: Diners can have different flavor outcomes with a Logic Bonbon depending on the logic function and flavor inputs.

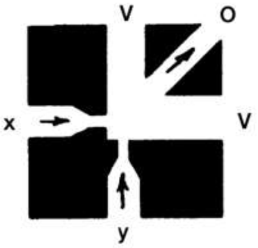
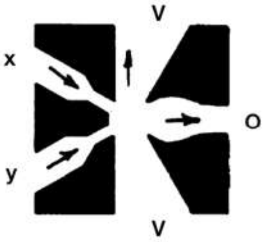
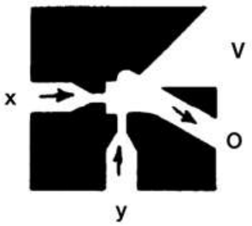
	AND	OR	XOR
Logic function	Output (O) if both inputs (x, y) are on	Output (O) if one or both inputs (x, y) are on	Output (O) if either inputs (x, y) are on but not both
Typical configuration of fluidic logic gate (Reid, 1969)			
Truth table	X Y O 0 0 0 1 0 0 0 1 0 1 1 1	X Y O 0 0 0 1 0 1 0 1 1 1 1 1	X Y O 0 0 0 1 0 1 0 1 1 1 1 0

Figure 8: A summary of three basic fluidic logic devices (AND, OR, and XOR) and the functions they perform.

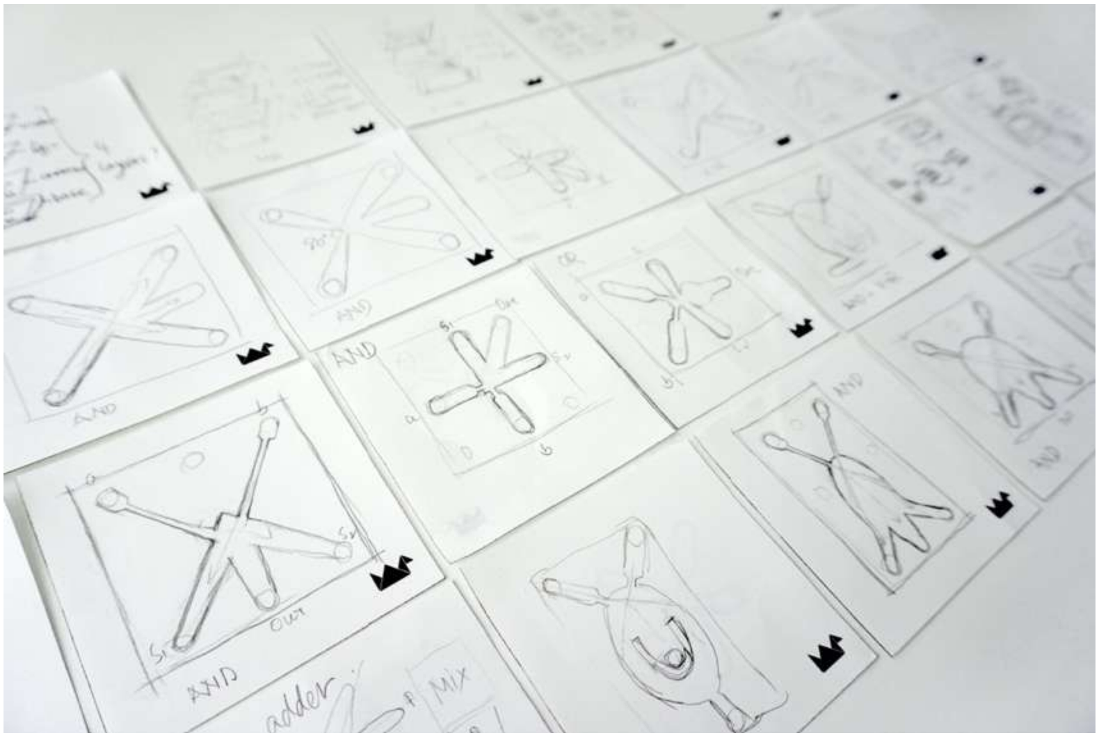


Figure 9: Sketches of various fluidic logic gate configurations.

Table 1: Participants' details along with age, gender pronouns, relationship, and self-rating as a "foodie" and "computer guru".

Household	Participant	Relationship	Self-rating as "foodie"	Self-rating as "computer guru"
1	P1 (33, F)	Friend	9	5
	P2 (32, F)		6	8
2	P3 (32, F)	Partner	9	7
	P4 (31, M)		10	8
3	P5 (27, M)	Partner	10	8
	P6 (32, M)		8	8
4	P7 (28, F)	Partner	6	7
	P8 (28, F)		8	9
5	P9 (26, F)	Partner	7	5
	P10 (30, M)		6	7

Logic Bonbon to make a complete system. They were requested to try out the three different logic gates and eat the Logic Bonbons. A researcher frequently checked on participant progress and asked them questions, such as: "*What does it make you think about?*" and "*How do you feel when you touch/smell/taste it?*" These questions were intended to help us better understand participants' initial perceptions of the Logic Bonbon. Second, participants undertook a co-eating activity, in which they were asked to recreate a new system to eat the Logic Bonbon they had made during the first activity. They were asked to collaboratively trigger a logic function and share the Logic Bonbon with each other. Again, a researcher asked questions such as: "*How do you feel?" and "How did the computational logic affect your experience back to the moment when you. . .?*" The purpose of these questions was to learn about their social experience of preparing and eating the Logic Bonbon.

5.3 Data Collection and Analysis

During the study, participants were observed from a distance so that the researcher minimized any interference with the assembly process. Photo and video recordings of the entire process were collected with participants' consent. Participants were then interviewed using a semi-structured approach [59]. Finally, the video, photos, and interviews were analyzed using an inductive thematic analysis approach [16]. All interviews were transcribed and then coded. We used open coding with the purpose of identifying key themes among the participants' descriptions of their experiences.

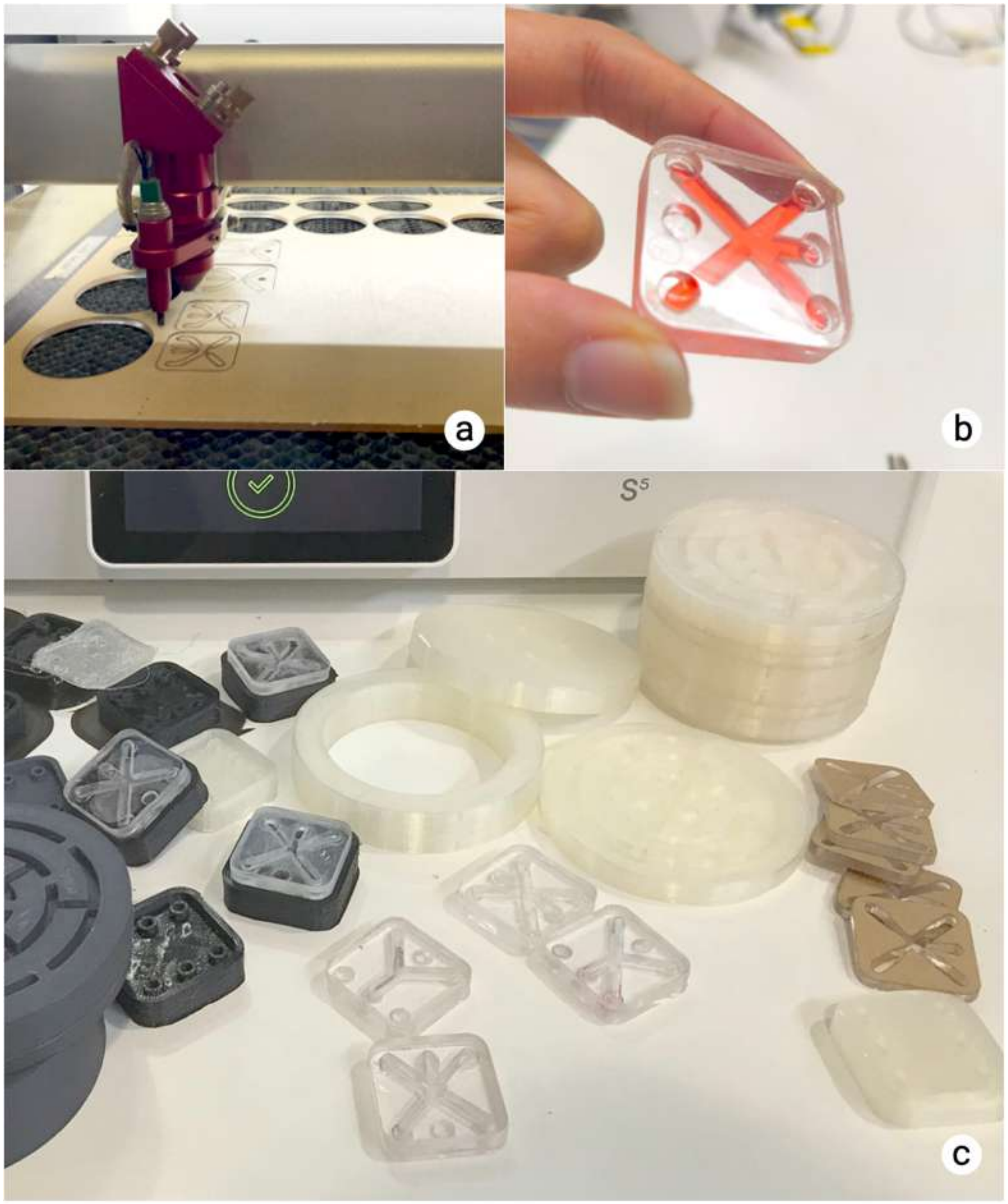


Figure 10: Making process of logic gate devices: a) Laser cutting various configurations of logic gate designs. b) An initial design of an assembled logic gate device. c) Various fabricated designs of logic gate devices.

When coding the transcripts, we looked for recurring themes and our findings encapsulate these themes.

5.4 Findings

Our study has brought to light 18 findings (F1-F18) that have been clustered into four themes. Overall, participants enjoyed the experience and found that the Logic Bonbon was tasty. The approach of food as a computational artifact appears to have generally enriched the participants' eating experiences.

5.4.1 Theme 1: A Diversified Gastronomic Experience.

- F1: Appreciation of the diverse flavor experience afforded by computation

All participants agreed that they enjoyed the diverse experiences that the computation allowed for in their eating. For example, P4 applauded that there were different "sort of flavors I would get" as diversity in their food was important. To further elaborate, P4 said: "You don't want to have the same food all the time. Otherwise you'll get bored." P5 added: "Because there will be different outcomes, it keeps you intrigued about, like, what if I changed my force a little bit, what flavor would [it] be? For example, when you do the whole process by yourself and you know that there are three different

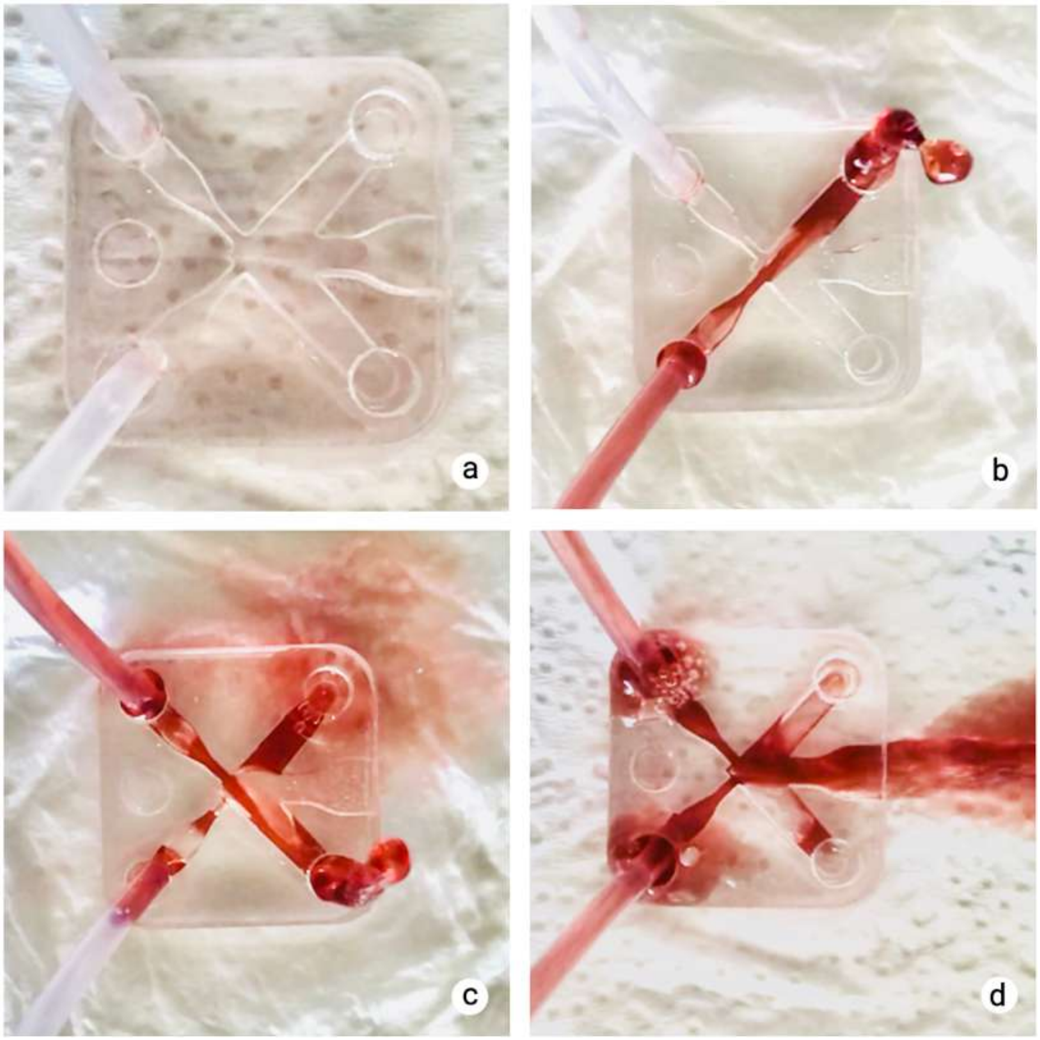


Figure 11: An example of testing an AND gate. a) The logic function returned FALSE if both inputs were off. b-c) The logic function returned FALSE if the fluid went out from the vent port when only one input was on. d) The logic function returned TRUE if the fluid went out from the output port when both inputs were on.

[possible outcomes of] flavor at least, like strawberry, 'strange' or orange." Participants also pointed out that: "Instead of it being a binary thing, in terms of a complex input like this, you would get all kinds of different permutations and you couldn't really use or be able to rely on anything for that, but it would be a way of being more creative to offer more chance" (P10).

- F2: The sound produced by the flowing fluid provides auditory feedback of computation

Participants pointed out that they noticed a "bubbling sound" (P6) that was produced while they were manipulating the fluidic reservoirs. This sound gave them immediate auditory feedback that computation was about to happen – that is, fluids flowing through the Logic Bonbon: "Because we can hear the sound with the Logic Bonbon [. . .] it [the bubbling sound] makes me feel like this food is more 'real"' (P5). P6 explained: "Because you can tell it's [the fluids] being injected into the Logic Bonbon by hearing, even if you can't see it, you can still understand that it's actually working because the sound represents that we are injecting something into it."

- F3: Appreciation of the visual display from the computation

The interviews suggested that the visual display from the computation enriched participants' experiences because it offered an additional layer of information to complement the feedback of flavor "that you're able to see [the flavor output] through the Logic Bonbon" (P4). Participants said that the visual display was "definitely adding the value" (P4) because "it's easier to tell whether the food is ready or not, because we can just tell by the visual elements. If it is filled up on the top, it is ready. While traditional cooking is a different thing because you have to try it out to test, to see whether it is well-cooked or not" (P5). Further, P10 also pointed out that: "it tastes more delicious because you bring it into the visual element".

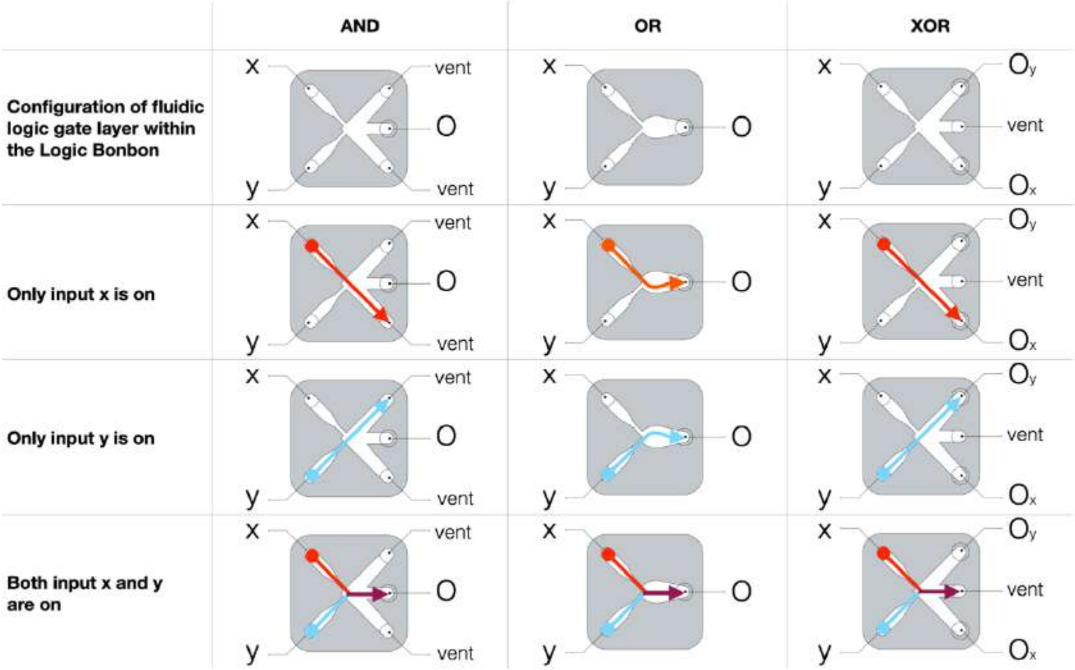


Figure 12: The actual configurations of three common fluidic logic gates along with their fluid flow.

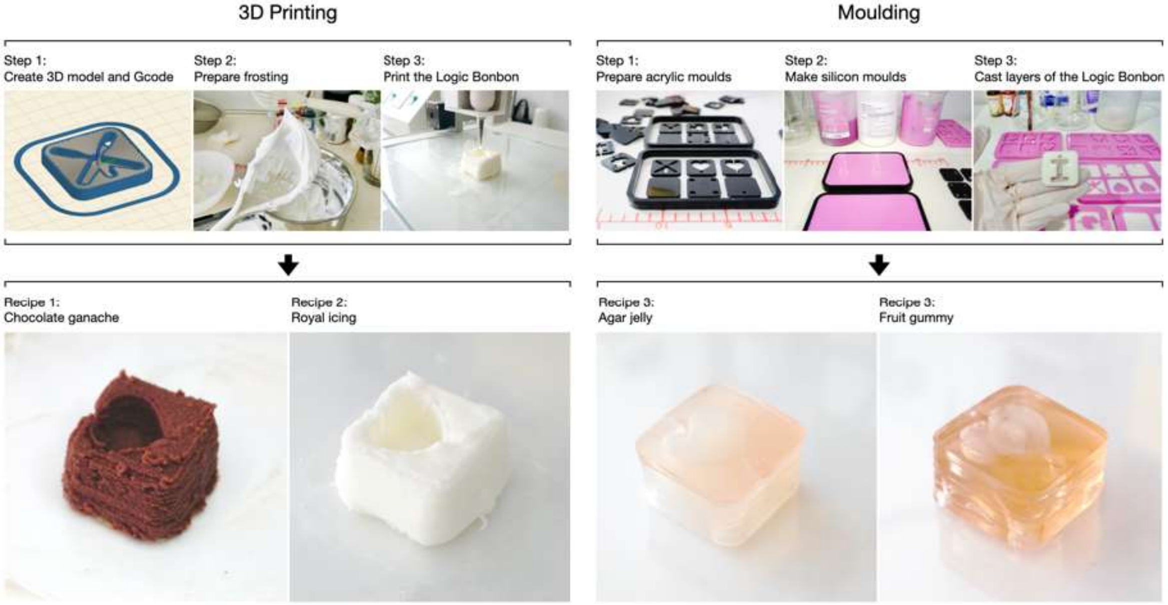


Figure 13: Exploring food materials and fabrication techniques: a comparison between food 3D-printing and molding.

- F4: The "slowed-down" process of "cooking" and eating increased the appreciation of the food

Participants indicated that the eating process was "more like cooking": "I feel like if you make the [Logic] Bonbon yourself, you're kind of cooking" (P10), and it slowed down the eating and subsequently increased the appreciation and exploration of the food. P6 stated: "It slow[s] your process of finishing the whole eating because if you just serve it and eat it, then you won't even feel the flavor or you will forget it quickly. You waste a whole process [. . .] If the process takes longer, the appreciation level will be enhanced". P5 added: "You want to cherish it more if it's produced by yourself,

Figure 14: Participants making and eating Logic Bonbons.

either you just slowly bite it or try to understand the flavor of it. This slows down the process in a way as well". Also, P10 stated: "The joy of the setting up the logic gates, like making it yourself would be just more delayed gratification". This observation suggests that the process of making the food as a computational artifact contributed to an enhanced appreciation of food that affected how participants engaged with it: they ate with heightened awareness, slowly taking it in. This extended time may have promoted a long-lasting appreciation of their food.

- F5: Appreciation of the overall flavor and interactive experiences that the Logic Bonbon afforded

Participants reported that they enjoyed the flavor experience of the Logic Bonbon. They particularly enjoyed the smell, temperature, texture, and taste of the Logic Bonbon. They reported that they tended to associate the Logic Bonbon with a nice dessert: "It just smells like a normal dessert to me" (P5). P3 also described the temperature: "It feels cold, like a dessert [. . .] with citrus flavor" (P3). P4 said: "[It] feels gooey [. . .] Like tofu with a very mild sweet taste". P1 also enjoyed the Logic Bonbon: "Because I love jelly, and I love gummy texture, it's something like my snack, I liked it". Participants also enjoyed engaging with the Logic Bonbon interactively. For example, participants made statements like: "It [the Logic Bonbon] enhanced the overall experience as well because it's more interactive" (P5).

5.4.2 *Theme 2: Personalization.*

- F6: Appreciation of the capability for flavor adjustment immediately prior to eating

All participants appreciated that the computation extended their ability to decide what flavor they preferred right up to the moment they began eating, which allowed for a "timelier" personalization when compared to a restaurant experience when they would need to decide the flavor they wanted when ordering. As P5 stated after the individual activity: "I can alter the final flavor by myself depending on my personal preference, this is good having the capability of altering the flavor by the end-user. Because in the restaurant you will be served a dish and it's really hard for you to alter or change the flavor anymore." P1 also said: "It is supporting evidence that the eating experience can be designed not only by the food provider but also the customer." P1 felt that this supported her desire to control how she wanted to eat: "With [the Logic] Bonbon system, customers can design their own experience right after food being served. I should be able to control the tasting experience that I want to have first."

- F7: Flavor personalization through a dynamic control

All participants agreed that the Logic Bonbon enabled them to design their flavor experience to meet their personal preferences. For example, P4 noted that: "[the Logic Bonbon is] useful for personalization, and I think that act of pressing was like a pressure parameter that facilitated personalized computation". Further, in comparison with the capability of personalization in traditional cooking and eating, P7 explained that the Logic Bonbon afforded more "dynamic changes": "You can see the flowing fluids and blending color when pressing the reservoirs respectively". P6 added that: "Unlike [the] normal cooking process [where] you cannot take out the flavor that has already [been] added in the food, here you can take more control, like you can take out the old flavor by squeezing new flavor in".

- F8: The computational process reinforced a personal attachment with food

Participants noted that they felt personal attachments to the Logic Bonbon during preparation and computation. P4 said that this "ownership" of food was important to him: "When you placed the layers, it didn't feel like our food yet, however, once I touched it [injected the fluids inside], I felt more like, ok, this is our piece of food that I was going to share with my partner" (P4).

- F9: The process of making as a coordination with computation by partially releasing the ability to control

Participants reported that they felt there was "an extra step here that's out of your control – that's the logic of the bonbon, no matter what you do, if it's an AND [gate], and you only press one [of the inputs] you can't get it to fill. So there's kind of limits in a way that was more taken out of your hands" (P10). P3 also describe that: "You can change it (the flavor and color) before the computation, after the computation, but not during the computation [. . .] when the logic gates are being computed". This brought a sense that the participants did not just perceive themselves as a diner, but also as a part of the computation when eating with the Logic Bonbon system: "It [eating with the logic Bonbon] was much more like a coordination, performing an action" (P10). A similar comment was: "You're more present with your food and definitely in the sense, like, you have to work for your food" (P9).

- F10: Appreciation of the reversable capability afforded by computation

P7 and P8 noted that the computation of the Logic Bonbon also heightened their willingness to try out new flavor combinations that they would not try with normal desserts: "I would be more willing to try out new flavors [. . .] the computation made me feel more confident and fearless of making mistakes as you got a chance to reverse and replace the added flavor by pressing the liquids out of the Logic Bonbon [through the overflow vent]. And it encouraged me to explore new things that I wouldn't explore before" (P8).

5.4.3 *Theme 3: Learning by Eating.*

- F11: Appreciation of the exploration afforded by the computation

All participants said that they enjoyed the fluidic logic functions' support for exploration, or, as P4 called it "experimentation", and P2 described it as "an adventure of new tastes". P4 explained: "The experimentation is important, as food is all about discovering, mixing things and experimenting", which he felt was supported by the Logic Bonbon. He also explained: "If I'm using an XOR [gate] that you naturally don't realize [the meaning of it] immediately [compared with the AND or the OR gate], that's where the experimentation happened, to understand what sort of flavor I would get into the [Logic] Bonbon". P10 explained the reason that people are interested in doing experiments is because "that's kind of how we learn when we have to teach ourselves to do things. I guess we kind of have to experiment [as] I couldn't really tell, like just intuitively how much force I would need to apply to make it go into a certain space".

- F12: The unfolding process of the hidden logic computation evoked a sense of suspense

The logic functions are hidden inside the Logic Bonbon, and the participants were not given any clue about what logic gate they got (i.e., what function it performs). For this reason, eating the Logic Bonbon system was a process that gradually revealed the logic functions in front of the participants. This unfolding process resulted in a surprising experience: "I liked to see how it unfolds, I liked to learn from how the liquids are flowing so I got to know whether it's an AND gate or an OR gate. So I'm more than happy not to know, so you have the surprise" (P3).

- F13: Participants appreciated the revealing of the hidden computational process

The interviews revealed that the Logic Bonbon made computation concepts more understandable by bringing the entire flow of operations to light. It appears that the engagement facilitated an enjoyable, memorable experience of learning abstract knowledge of computer science through food was facilitated. P3 explained: "It was the most interesting and enjoyable part to see something that often happens out of sight for us [that allows] what happens at the background to have it out front and be manipulated in a way to get to the outcome". P5 added: "You actually see the product [Logic Bonbon], and then you inject the input to receive different outputs, it makes more sense [. . .] And it enhanced the overall experience as well". In addition, the visual display differentiated the experience from a more conventional way of cooking and preparing food, enabling the "learning to be more visual" (P4).

- F14: Participants described a memorable learning experience through interactive food experience

Participants reported that the whole process of preparing, cooking and eating the Logic Bonbon has "boosted" (P5) their understanding and was "a unique experience" for them because "we do"t usually use food as a way for learning things" (P5, P6). Participants explained: "Because it's more interactive and it's easier for me to understand the actual meaning [of logic gates]." (P5). Further, P6 noted that the experience of learning by eating the Logic Bonbon reinforced the memory of what he learned: "You can always try out with different strategies to receive different results. It can boost your understanding in a way as well, so it will be a kind of a memory that I won't forget in the future"(P6). P10 also explained: "Because the hands-on aspect of it, like the fact that you're actually physically squeezing to do the logic functions, it's interesting because it feels like you're more intuitive and you're kind of part of the computation much more physically".

5.4.4 *Theme 4: Social Discovery.*

- F15: Enjoyable collaborative eating afforded by the Logic Bonbon

The participants appreciated the social engagement that emerged from co-creating and collaboratively eating the Logic Bonbon. Compared with eating alone, P3 and P4 said that they "definitely prefer to eat and share with other people, no doubt". P3 said that she "loved it [the co-creating activity]" and explained that the process led to a pre-discussion because "it requires a certain process that something needs to be done in a certain way". Similarly, P5 said: "It's like making a dessert by two of us together, when you do things together, you put feelings in that [food], and you always think more positively towards the food [. . .] I prefer eating it as a social game or interacting with other people, it would be more interesting if you have a team, [it will be] as an icebreaking activity we can do it together".

- F16: Eating the Logic Bonbon built up an experience of intimacy

The interviews revealed that the collaborative activity around the Logic Bonbon system built up an experience of intimacy. In the second activity, participants got a Logic Bonbon with an AND gate. Each dyad had to negotiate to decide the cue for pressing the pipettes to achieve the desired outcomes together. Most dyads decided to count "1, 2, 3, go", and one dyad tried to make a "rhythm" (P9, p10). It was also important that both participants in the dyad applied the same amount of pressure to the pipettes. Two dyads used a strategy of pressing each other's finger to confirm the same amount of force would be applied to the reservoirs and practiced mirroring the actions of their counterparts before eating. P3 stated that: "This having a conversation, and having a laugh is more intimate [. . .] and it's a different way for people to perceive intimacy [. . .] The whole process that contributes to the intimacy is to get things right, you have to control the pressure obviously, you have to touch each other to see how much pressure you want to give to perform the task [. . .] the touch was facilitated [for] how we get it right to get the system going". P10 added: "You're trying to synchronize activity with someone else that makes you feel closer to them [. . .] you see yourself as more similar to that person, I think it's because your brain is trying to work out who it's close to and who it belongs with [. . . and] it makes you feel connected [with the person]".

- F17: Participants shared the Logic Bonbon that they co-created in various ways

In the second activity, after participants co-created the Logic Bonbon, they were observed engaging in different ways of sharing the desserts with their partner/friend after they co-created the Logic Bonbon. For example, two dyads cut the dessert in half to share it with each other. Another dyad split the logic Bonbon layer by layer and shared the two chamber layers (with a "heart" icon) with each other. The rest shared the Logic Bonbon by biting half of it. P5 explained: "I could just take one bite and give the rest to him [my partner]".

- F18: The different logic functions promoted different forms of playfulness through eating together

The co-eating activities revealed that eating the Logic Bonbon with different logic functions increased the playfulness of eating. For example, an AND gate encouraged collaborative play as each dyad had to negotiate the cue for pressing the pipettes, and to ensure that both dyad participants applied the same amount of pressure so that they could achieve the desired outcomes: "We need to work with each other to complete the task" (P7). P10 stated: "[Eating with an AND gate] there's definitely more of a sense of satisfaction in achieving something for the co-operative mode, it's more complicated to coordinate". On the other hand, participants demonstrated a more competitive eating behavior when using an OR gate, as P9 explained: "The AND gate was to be collaborative, whereas this one [the OR gate] don't collaborate". It appeared that participants tended to challenge each other to press more fluid into the Logic Bonbon: "I liked to see that more fluid on my side flows into the Logic Bonbon as I can get more flavor that I like, so I felt that I won the game" (P8). Participants also explained that the competition was still fun because it was "like a game" (P9), and "even though that's a competition, it's not like where two athletes trying to beat each other at the Olympics, it will never take it that seriously so the competition would never be that fearsome" (P10).

6 DESIGN CONSIDERATIONS

Based upon our research designing, crafting and studying the Logic Bonbon, we now reflect on our findings and focus on the implications of these findings for future design. We have formulated an initial set of design considerations that are relevant to the creation of engaging human-food interactions with food as computational artifact.

6.1 Utilize the "dynamics" as a design resource of food as computational artifact to facilitate more diverse food experiences

The design practice of creating the Logic Bonbon uncovered a dynamic quality of food as computational artifact that afforded a diversity of engagements with food. We suggest that designers use these dynamic qualities as a resource when designing food as computational artifact so that it supports creative, playful, and social as well as multisensory engagements with it. Löwgren and Stolterman described interactivity in terms of an artifact's "dynamic gestalt" to highlight the "emergent properties" in describing its "overall character" [50]. Wiberg [95] subsequently suggested that "dynamics" refers to an "ability to change through use and to communicate a change of state to its user" which can be "deliberately designed". In this respect, Wiberg argues that there are two purposes that the "dynamics" of an interactive artifact serve: enabling an interaction, and communicating a change of state [95]. Reflecting on the

Logic Bonbon, the design highlighted two aspects relating to the "dynamics" of food as computational artifact – *variable triggering* as the enabler of the interaction and *sensory transformability* as the communication of state change.

6.1.1 Variable triggering. As enabler of interactions, the "triggers" we generally encounter on most interfaces are levers that push onto a button to form an electrical connection. In such cases, the "dynamic-ness" of the interaction is limited because the options are merely on or off; only one output can be triggered when the trigger is depressed or not. With respect to the design of the Logic Bonbon, the changes to its flavor/color can be triggered by squeezing the flavor reservoirs. This trigger affords diners a diverse form of engagement not only through initiating the computation and enabling a change of state, but also through acting as a pressure sensitive trigger and allowing various (non-binary) input signals. We characterize this quality as *variable triggering*. Our findings revealed that the engagements with food through *variable triggering* were diverse, ranging from eating in creative ways, to playful ways, and even to social ways. The range included enabling diners to compute various flavor combinations through creativity (F1), supporting a delayed gratification (F4), facilitating various ways of play (F18) and social engagements that built up a sense of intimacy (F15, F16, F17).

6.1.2 Sensory transformability. The Prior works with transformative foods [75, 89] have realized the geometrical changes of a food's visual appearance through cooking. With respect to the Logic Bonbon, diners can not only dynamically control its visual appearance through the display layer, they can also change its flavor in real time based on the pressure and pace applied to the flavor reservoirs (F7). These dynamic changes to sensory properties allow diners to be continuously intrigued in a multisensory way: when touching the flavor reservoirs to control the pressure (F7); when hearing a "bubbling sound" to understand the right timing to eat (F2); and when visually perceiving the outcomes of flavor feedback (F3).

Thus, the *variable triggering* (as enabler of interactions) and *sensory transformability* (to communicate change of state) are two essential aspects when considering the dynamic qualities as a resource for designing food as computational artifact. We acknowledge that further studies will be necessary to corroborate our contentions.

6.2 Consider the Temporality of Eating for Real-Time Personalization

The study demonstrated a "timely" manner in personalizing food experiences with the Logic Bonbon. Personalization is an alternative to homogenous offerings, whereby consumers get something that is just right for them. While digital technology has boosted our capability to design food products that are computationally preconfigured to meet consumers' individual preferences [105], many diners would still be familiar with the experience of having selected a dessert then, only moments later, realizing that they would prefer a different option. That is, most current personalization only occurs during the production process, e.g., during cooking. Therefore, we suggest designers consider the temporality of real-time personalizing food experiences that characterize the overall diner experience and feelings associated with specific timing when designing food as computational artifacts.

We argue that the traditional "in-process" personalization is only one part of the equation considering that today's consumer path has become increasingly dynamic and unpredictable. We use the emerging term "micro-moments" [73] to describe the personalization that takes place in the "intent-driven moments of decision-making and preference-shaping that occur throughout the entire consumer journey" [62]. These moments include when a diner picks a product, decides to place an order, has the food item prepared, and is ready to eat. With respect to the Logic Bonbon, our findings showed that diners not only have these choices when placing an order online, or as the food is prepared in the kitchen, but also when it sits in front of them at the table, and even through to the final moment before they eat (F5). However, we also note the potential disadvantage for real-time personalization, that is it might interrupt the dining experience and challenge people with too much choice during the eating process [71].

6.3 Embracing "Prosumption" to Enrich the Engagement of Learning by Eating

The findings indicated that combining the eating process with cooking practice can be seen as falling under the concept of "prosumption" as introduced by Toffler [78] who foresaw the reunion of "production" and "consumption" in the post-industrial era. Aligned with Jayaprakash et al. [40], the idea of prosumption allows chefs and businesses to create dishes and food products with "high desirability value" and thus, "improve and enrich the consumption experience" [83]. This idea has informed the upward trend of "DIY (do-it-yourself)" and "RtC (ready-to-cook)" subscription food delivery parcels that allow customers to produce while consuming their own food products. The Logic Bonbon has extended the concept of "prosumption" from simply "do-it-yourself" home cooking and dining to allowing diners to participate productively within the entire assemblage which now also includes a computational cooking mode. We suggest that designers embrace the concept of "prosumption" highlighting two aspects in designing food as computational artifact: *human-food-computation coordination*, and *transparency of computation.*

6.3.1 Human-food-computation coordination. Human-food-computation coordination includes pre-design and customization (i.e., selecting the Logic Bonbon with certain logic gates, flavor and ingredients), creation (i.e., building the system), cooking (e.g., executing the computation through input actions), and eating (e.g., sharing with others). Our findings indicated that the process of coordination appeared to be able to promote an engaging experience through "learning by eating" (Theme 3). Furthermore, participants expressed a strong personal attachment to the food via their exploration, which evoked a long-lasting appreciation of food (F4) in the sense of the participants' time, energy, and skill being "freely and productively used" and progressed [83]. However, we acknowledge that some may argue that the "prosumption" might "weaken consumers" by "exploiting" their labor [65], leading to an overwhelming experience for those who just wish to enjoy their meals without additional efforts.

6.3.2 Transparency of computation. Our findings also suggested that the *transparency of computation* – including both the transparent property of the Logic Bonbon and the flow of the process – allowed diners to optically see, and therefore be more to likely understand, the computation and hence how their food was generated, i.e., "computed". The *transparency of computation* supported an enjoyable participant learning experience (Theme 3) via their "behind-the-scenes" look at basic computer science concepts, and through a multimodal engagement with food from the combined "cooking & dining" process: they began by touching the flavor reservoirs to control the pressure (F7), then heard a "bubbling sound" indicating the right time to eat (F2), and they visually perceived the outcomes of the flavor feedback (F3). They finished by tasting the computation. This experience was in line with the research into enhanced learning from multimodal training, which it was reported that simultaneously engaging learner's senses through multimodal interventions can enable a more effective learning experience [66, 91]. Nevertheless, we acknowledge that such transparency might also distract some diners who might focus too much on "how it works" rather than "how it tastes".

6.4 Consider Episodic Moments as A Ritual of Social Eating for Promoting Enjoyable Mealtimes

We concur that the social engagement of eating "provides an opportunity to reinforce values and norms and strengthen communal ties" [9]. In response, prior works presented various social eating systems highlighting the commensality and social presence of computing technologies [8] [93] [51]. Such social eating systems mostly focused on specific interaction events and paid less attention being paid to how the user experience evolves over time. Beyond the general "togetherness of eating," our findings highlighted the tiny moments of magic throughout each touchpoint when eating the Logic Bonbon: the intention with a conscious beginning (i.e., decide a co-eating strategy), middle (i.e., co-discover the process of computation), and end (i.e., share the Logic Bonbon). Prior research presented that enacting ritualized actions as an emotionally significant practice can heighten our enjoyment of food [87]. We see these episodic sequences of actions [77, 87] as rituals taking place in the secular setting of social eating. We suggest designers consider the impact of transforming moments on diners' actions when engaging with a system in a social eating context. We identified three "episodic moments" in a social eating context of practicing the ritual when eating food as computational artifact – *synchronization*, *cooperation*, and *mutualization*.

6.4.1 Synchronization. Synchronization refers to the initial moment before the first encounter. Our study observed a series of actions relating to the way diners approached the system and prepared to use it. For example, some dyads had a "pre-discussion" to decide the cue for when to start pressing the flavor reservoirs, while others pressed each other's finger to confirm the same amount of force would be applied to the reservoirs, and others practiced mirroring their pressing actions. All these actions served the same goal: to successfully execute a logic function. Participants were trying to "synchronize" their actions to determine the right timing and pressure to trigger the computation. We found that moments of synchronization can reinforce participants' personal attachment to and positive feelings toward their dish and build up a sense of intimacy (F7, F14).

6.4.2 Cooperation. When the actual moment of co-eating began, the diners were able to collaboratively "cook", explore, and discover the computation and flavor with a limited flavor reservoir (each participant only had one for each round). This *cooperation* afforded by the Logic Bonbon offered a "co-discovery" and slowed-down eating experience, facilitating a heightened awareness that might have promoted a sense of surprise, playfulness, and possibly even a long-lasting appreciation of their food (F10, F16, F9).

6.4.3 Mutualization. Mutualization refers to the epilogue moment when diners enjoy the "fruits" of their mutual labor. With each dyad of participants only being able to access one flavored Logic Bonbon at each round of their co-eating activity, we observed various methods of sharing at the moment of eating (F16), with increased playfulness (F17). Our findings suggested that performing this mutualized ritual of food sharing possibly heightened the willingness of participants to become involved, and led to positive associations with the overall eating experience.

These moments often taking place episodically and in sequence, can usually be identified when people are urged to make a pivotal decision, or when there is a transformative effect on diners' perceptions and behaviors through social activities. If we can identify them, we can intentionally design and ritualize the episodic moments of social eating for promoting enjoyable mealtime, such as team-bonding challenges, romantic diner for a date or a family warm up game for thanksgiving party.

7 DISCUSSION

7.1 Design Challenges and Opportunities of the Logic Bonbon

One of the biggest challenges in this design work is the interactive fluidic mechanism: the inherent turbulence of fluid flows within the Logic Bonbon – characterized by recirculation, eddies, and seemingly randomness – sometimes led to unpredictable logic function performance. Even minimal changes to the fluidic channels, or to the pressure being applied, could result in different outcomes. Consequently, the results executed by the Logic Bonbon thus cannot always be seen as binary in the same way as traditional logic gates. For example, we observed that the Logic Bonbon did not just execute a state of two mutually exclusive conditions such as TRUE (1) or FALSE (0), there were also intermediate states represented by a variable flavor outcome. These occurrence of these states mostly depended on the pressure applied by the diner. They also occurred as a result of inaccuracies arising from the fabrication process and the coarseness of the food material. Consequently, it appears that we cannot expect to always have a distinct flavor outcome within a Logic Bonbon. However, we see such unpredictability and intermediate states not only as limitations, but also as opportunities, whereby uncertainty opens up a particularly exciting (yet challenging) area for future explorations into the design space of integrating fluidic computation with food.

Furthermore, the current exploration of the Logic Bonbon focused on the interactions of individual units of single logic operations. This focus may have limited our opportunities to use the logic gates to create more complex computational outcomes. Consequently, we believe that the extensions of more sophisticated logic circuits opens a huge opportunity for exploring more advanced food-computation integration capabilities.

7.2 Limitation & Future work

7.2.1 The Materiality of Food. Food is often fragile (e.g., crushing crisps), unstable (e.g., sugar that has gotten damp) and ephemeral (e.g., limited shelf-life). Working with food-based materials brings design and fabrication challenges. In the case of the Logic Bonbon, the ingredients suitable for the fabrication process restricted the food's palatability and aesthetics. The qualities of the material (i.e., its stiffness, elasticity and durability) essentially determined whether the computation could be properly implemented. Future exploration of food properties such as physical-chemical properties (e.g., electrical and thermal conductivity) and kinetic properties (e.g., biological changes and growth) might be useful for an additional understanding of food as computational artifact.

7.2.2 The Extension of Food-Computation Integrations. This case study has explored basic fluidic logic gates to understand food as a computational artifact. We acknowledge that this study provides only one example for realizing food-computation integration in the underexplored space of food-computational integrations that we have identified in section 2. Future work can further explore other forms of food-computational integrations, such as their "adaptation" capabilities.

7.2.3 Alternative Contexts. Our study of diner experiences has focused on the quotidian family eating scenario. It remains to be asked how food as computational artifact could be engaged within alternative contexts, including different dining environments and situations. Furthermore, future studies should also consider involving chefs and creative practitioners, so we can benefit from their broader culinary and gastronomic literacy and gain a better understanding of food as computational artifact.

8 CONCLUSION

This paper demonstrated a novel design of an interactive eating system – the Logic Bonbon – which exemplifies the prototyping of food as a computational artifact. Through both an experiential study and reflection on our design practice, this paper contributed a provisional account of how food as computational artifact can mediate new interactions through a novel food-computation integration, that promotes an enriched future of Human-Food Interaction.

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