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Master's Thesis
Academic Year 2022

Digital Food Printing Methods to Improve Malnutrition

Keio University
Graduate School of Media Design

Jian Pan

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

Jian Pan

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Abstract of Master's Thesis of Academic Year 2022

Digital Food Printing Methods to Improve Malnutrition

Category: Design

Summary

Nowadays, choosing a nutritional supplement product for nutritional deficiencies has often been the first choice for people with malnutrition issues. However, the results are often lower than peoples' expect because people are often not able to insist taking them every day. Some people think that they are already sick if they require to take nutrition supplement products everyday . There are also some of people forget to take them because of the fast pace of life today. Therefore, it is crucial to make people more willing to take nutritional supplements and also to help them build a long-term nutritional intake habit. In addition, since people's nutritional intake varies from day to day, the same amount of nutritional intake each day often leads to low efficiency. Currently, the use of 3D food printing technology is able to intelligently adjust print materials and add amounts of nutrients to food print. However, since this technology is still in the research and development stage, it is not available for use in people's daily life. In order to enable more malnutrition sufferers to have simple and efficient nutritional intake in their daily lives, this study will propose a user experience design for customized food print. We will simplify the current complicated 3d food printing process by designing an app to assist food printers, so that people can use it anytime and anywhere even in their homes. In addition, we will provide visible nutritional intake data in the app to facilitate users to be more aware of their changeable health status. In this study, we believe that designing playful and enjoyable dining experiences for users who have negative feelings towards nutrition supplements will transform their original attitudes to positive emotion and allow them to spontaneously and proactively take daily nutritional supplements to develop long-term habits.

Keywords:

3D food print,malnutrition, dietary habits,customization, dining experience

Keio University Graduate School of Media Design

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Chapter 1
Introduction

1.1. Malnutrition

1.1.1 Background and Motivation

Nowadays, with the development of medical system, the current health status of world has already achieved a relatively high level.In 2016, Japanese life expectancy between the men and women at birth was respectively 80.98 years and 87.14 years. [1] After one year, Japan achieved a high scores on 40 health-related Sustainable Development Goals (SDGs) and was categorized as having low levels of regional disparities.

However, according to the study, 21.5% of women aged 15 to 49 years are currently affected by malnutrition, which is responsible for 9.5% of newborns born with low birth weight. When the effects of pregnancy are not taken into account, 7.1% of children under the age of 5 still suffer from obesity or undernutrition due to malnutrition. More than 1.04 million children in Japan today are still reported to have malnutrition diseases. In 2015, the malnutrition rate among preschool children was 13.45%. And according to the National Nutrition Survey from 1948 to 2005, Japanese girls are more likely to be overweight in childhood, but getting thinner during the younger age. [1] Therefore, it is imperative to tackle the problem of malnutrition in Japan.

1.1.2 Dietary Habits and Malnutrition

After childhood, adolescence is the second significant developmental stage in people's whole life. During adolescence, people tend to grow in a more rapid mode, and their body composition changes accordingly as well. This usually leads to

increased energy and micro-nutrient requirements. The eating behavior of adolescents might be affected by sociodemographic characteristics, such as socioeconomic level, education level, and gender. [**?**] The eating habits established during adolescence tend to keep in adulthood. In addition, dietary habits adopted during this period will cause great contribution in future health outcomes. However, nutritional deficiencies during adolescence can also lead to growth retardation, impaired organ remodeling and micronutrient deficiencies, among other sickness.

Currently, people often choose the appropriate nutritional supplement products to treat nutritional deficiencies. However, according to a study conducted in Mexico, the single-nutrient approach has been confirmed to have some limitations. Specifically, they examined adolescent dietary intake based only on glycemic index, single nutrient intake, and food group consumption at the national level in Mexico, including 8768 boys and girls under the age of 25. Dietary patterns offer us greater diversity of dietary and nutrient combinations, including antagonists, additives and synergistic effects of food matrices [19]. Therefore, the dietary pattern approach is a better option to study the interactions between diet and malnutrition problems.

1.1.3 Malnutrition Consequences

Malnutrition in all its forms, including under-nutrition, micro-nutrient deficiency, and overweight/obesity, is one of the major causes of global health burden. Common signs of malnutrition include: unintentional weight loss , a low body weight, and a lack of interest in eating and drinking.(Fig:**??**[1]). People who have malnutrition usually are feeling tired or weak in daily life, and easy to get sickness and always takes long term to recover. Thus, a series of chain reactions will be triggered, such as decreased immunity, slow behavioral and intellectual development, and even serious food allergies, which can lead to long-term sub-healthy condition during their growing period. [2].In addition, micro-nutrient deficiencies and overweight/obesity are major contributors to the global health burden.

For instance,according to recent studies, there is a significant increase in the incidence of unintended weight loss and malnutrition among hospitalized patients

1 `https://smartplatenutrition.wordpress.com/tag/malnutrition-awareness-week`

in the current COVID-19 pandemic. These factors can also increase the length of stay and medical expense and occupy numerous of medical facilities, thus cause a great strain and pressure on the current healthcare system. [3].These studies sum up a persistent and highly underestimated problem for us. Due to the lack of adequate risk screening awareness, malnutrition often goes undetected.

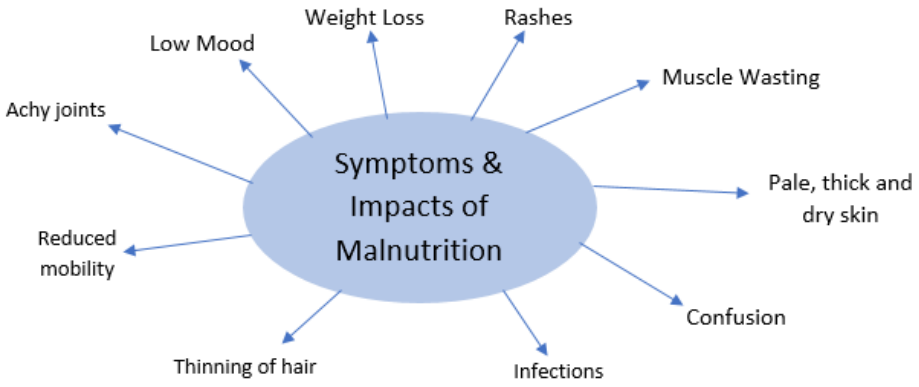


Figure 1.1 Printed Malnutrition Chart

1.2. Food Print Technology

1.2.1 The Rise of Food Customization

In the current food service industry, food customization has become the latest trend. Rather than picking the satisfied meal from a massive menu, 20th century's consumers are more prefer food items which are fresh, creative and made just for them. In fact, people often choose to go for something unique when they go to a restaurant. When it comes to food variation, 72% of consumers expect food customization. [2].

According to the research, it shows that the numerous selections in the menu makes people less likely to pick something, and even they actually make the choice,

2 https://primeroedge.com/2017/08/15/the-rise-of-food-customization

usually they are not quite satisfied with it. When people have to face so many choices, people often get an 'analysis paralysis' and even feel aversive to select anything at all. [3].When it comes to the have-it-your-way generation, customization is key.Customization allows young generations to feel like they're out of the control – and since they're more independent than previous generations, innovation of customized service usually help food industry to earn greater attention.

For example, the following diagram demonstrates a conceptual project design of a food customization app for Japanese restaurants. ()The hypothetical restaurant was according to a typical Japanese ramen restaurant in Hong Kong. In order to enhance the customers' dining experience, this app design offers abundant combination forms of some typical Japanese ramen and allow customization. Customers can freely combine 3 types of soup, noodle thickness and firmness, and 16 toppings to create their favorite ramen cup. According to store survey feedback, customers always expect fresh flavors when they come to the store and do not get tired of the rich variations.[4]).

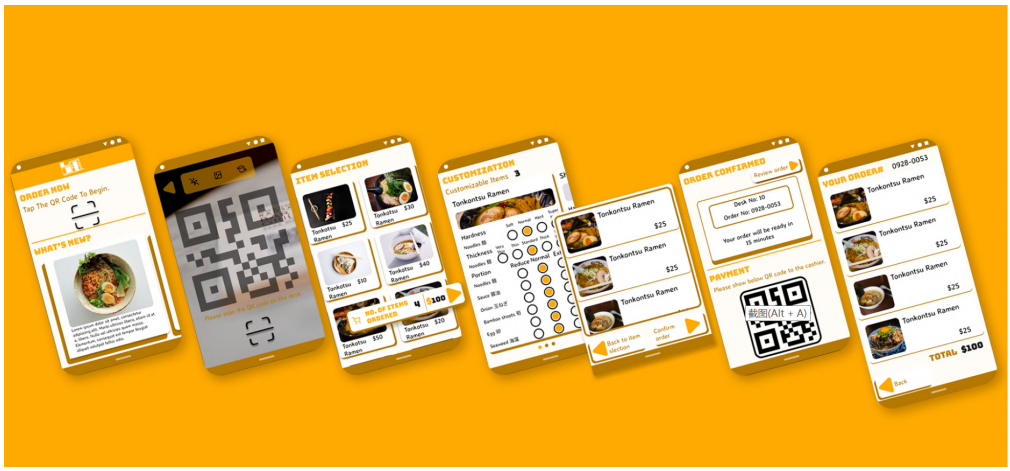


Figure 1.2 Food Customized App

Food customization often allows for abundant customization by providing customers with a wide range of food ingredients and toppings. On the other hand,

3 https://recipe-book.ubiregi.jp/articles/inshoku-customize-style

4 https://www.tonytklam.com/ux/design-a-food-customization-app-for-a-japanese-restaurant-2

customization can also leads to complicate operations. This is why it is rarely used for a long periods in people's life.

1.2.2 Food Production Automation and Food Print

With the widespread use of customized food services, some people are becoming aware of the lacks of complicate operations from food customization. Then they developed a new technologies to overcome this problem which is food production automation. Food production automation allows for more consumer specific data to be easily integrated into the food preparation process. This will undoubtedly improve the quality and utility of the food. 3D printing is one of the ideal family of technologies to enable such mass customization of food manufactures. [4]

Food printing was originally developed by some overzealous futurists. 3D food printing is actually an extra extension of these users' interest and a reasonable use of 3D printing methodologies.Currently, 3D food print are mostly focused on improving the artistic quality of food in the short term and the consumers' health level in the long term.It has a beneficial impact on human health by combining automation and consumer-driven data to provide consumers with food that is visually, tastefully appealing and customized to their desires and requirement. [5]

Papers from Jeffrey I Lipton [6] also mentioned with some specific reasons of advantages for choosing the food printing techniques to human health as two key factors, which are geometric complexity and mass customization.The ability of geometric complexity leads to produce highly complex shapes and material property distributions allows for parts with better performance than usual manufactured analogues. On the other hand, he also claimed that mass customization of food by food printer will enables the individual data driven production of foods towards customers. In other words, a potentially trans-formative impact will be received on human health. For instance, automation in the manufacturing of custom on required food materials will be efficient to help avoid the spread of food borne disease by eliminating disease source while allowing for the easy integration of consumer data. This has led to the widespread use of 3D food printing technology for food customization in the medical field.

1.2.3 Improvement of Current 3D Food Print

3D food printing processes all commonly require a single processing step to transform the material into its final shape. [7]3D food printing actually has a similar process to regular 3D printing. While this analogy is a kind of useful feature from a printing process perspective, it makes it difficult to integrate 3D food print into the kitchen or elsewhere.

With the development of the current Internet era, the application of individual biometric data is becoming more and more prevalent. And this also illustrate that we have the possibility to adjust the content of food based on users' individual health data, ,activity levels and their taste preferences. Some of the variables such as vitamin, nutrient and allergen content, calorie and portion size are able to be regulated and controlled through automated production as well.[5].

Users are ought to take control of their daily routine. They can customize dietary and nutrition intake every day according to their own requirement. In my opinion, if users can conveniently and simply use customization service to adjust their dietary and life, the more they can build a long-lasting habit by using this service, thus also provide a good protection for their physical health.

On the other hand, 3d food printing technology is also subject to some limitations in terms of printing materials. For example, 3D printers that operate like dough extruders are only able to print purees or mixtures that have good liquidity. Not all contents that compact fibers into fabric (especially meat) can be 3D printed as same as some fruits and vegetables. It has to be mashed or powdered which depends on the process used. [8].After complete the print mission, most food must also be heated before they can be eaten. Moreover, most current 3d food printers only equip one extruders. This has led to the following problems:

- Food printing takes a relatively long duration.
- Currently it is not possible to do multiple print jobs with one printer.
- Food printers are not able to print in multiple colors.

5 https://www.lapatisserienumerique.com/en/2020/06/pros-and-cons-of-3d-food-printing

Therefore,in future study, we are also able to focus on food printing materials, colors, feasibility of easy food print, and design concept of multiple customized food print.

1.3. Proposal

1.3.1 Research Purpose and Design Hypothesis

In this study, people will learn to use a customized food printing service to replenish their missing nutrients and improve their health status. The main objective is to avoid users forgetting or failing to insist to do the daily nutrition intake. Based on previous research studies, we propose the following design hypothesis. Nutritional balance can be better achieved through a combination of nutritional supplementation and dietary pattern approaches.

- Nutritional balance can be better achieved through a combination of nutritional supplementation and dietary pattern approaches.
- Intelligent and visible users' health data is more efficient than taking constant supplements day by day.
- A playful and enjoyable user experience will makes users feel easier to get into the habit of nutrition supplement and stick to it.
- Abundant customized food print will give users a good visual and taste experience.
- The geometric complexity used in 3d food printing will give the user a different experience from conventional cooking.

1.3.2 Summary of Key Contributions

The study is designed to customize nutrients through 3d food printing technology for achieving effective supplementation and also provide a enjoyable dining experience to malnutrition sufferers. 3d food printers will be collaborated with an support application to help users simplify the food printing process and offer

real-time and reliable physical health data. This is an unprecedented attempt. The paper mainly consists of 9 chapters, including this one. Chapter 2 presents case studies from this research, including existing 3d food printing and nutritional supplement products or services on the market in the current stage. In addition the findings and inspirations of this study will be described into a comparison with related studies as well. In chapter 3, the design concept is described in detail including three parts which are the design flowchart, software design and hardware design. In software design, it will show the ui and ux design in details which containing with the interaction methodology and different using scenairos. In hardware design, the assembly process of the food printer is documented in detail as well as the discussion and conceptual design of the parts and future technical improvements of the 3d food printer.

Chapter 5 describes the prototype processes based on the Perspectives in Chapters 3 and 4. It roughly covers print materials, colors, print forms, print shapes, taste effects due to added nutrients, main findings and conclusions. In Chapter 6, the service developed in this study is experienced by the users and the process is analyzed through questionnaire results and user feedback.

In chapter 7, the previous research questions and design hypotheses will be used to verify the completion of this study and find directions for future improvement. In the chapter 8, we will classify the factors that influence the 3d food printing technology, such as functions, target users, and using scenarios. Chapter 9 is the final chapter, it is devoted to the future prospects of the technology and its practical applications.

Chapter 2
Previous works

In this chapter, we will discuss the current utilization of 3D food printing technology, and list up some typical examples of 3D food printing and nutritional supplement products or services with high popularity. This chapter reviews many previous researches on the application of 3D food printing technology and how it can improve human's mood by modifying their dietary. Finally, we will analyze and conclude the existing research in order to summarize the novelty and value of this research.

2.1. Literature Review

2.1.1 Digital Gastronomy: Methods and Recipes for Hybrid Cooking

Nowadays, we are able to see there is a growing number of projects introducing digital technologies into the kitchen in forms of food printers, robotic chefs, or some theoretical studies of culinary recipes by learning the relationship between semantic and procedures. As many as the new developments in digital cooking demonstrate a high level of technical complexity and tend to favor the quantitative , as well as simplify the culinary culture. And these projects claim that cooking can be represented by a limitation of instructions, which can then be procedures analytically.[1].

However, Although the vision of digital cooking is not that of new, the potential of computers to improve our cooking and quality of life still remains a huge

1 https://foodandnutrition.org/kitchen-tools/a-hybrid-cooking-tool-for-all-your-culinary-needs

challenge. Therefore, we deploy existing kitchens of digital manufacturing tools in traditional kitchens and integrate them into cooking through hybrid recipes. The concept combines with the manual and digital processes and imports parametric design tools into cooking. This allows chefs to feel free to customize the taste, flavor, structure and aesthetics of their dishes.

In this research [**?**], Moran Mizrahi and her fellows set their purpose as stimulating and enriching human creative practices, seeking a method to merge with the traditional cooking and digital tools. They believe that the use of computers in the kitchen can ease and accelerate the discovery of new flavors, shapes, which are really difficult to achieve through traditional cooking methods. Therefore, a hybrid approach was proposed. They developed a kitchen featuring traditional and modern cooking tools. It arranges computer and digitally controlled devices side-by-side, and makes all items become a part of the chef's creative palette. (see Figures 2.1). (Fig:**??** [**?**]The chef is able to leave certain elements of the dish unfixed. When the guests make their own choices, they can fix these elements according to their individual nutritional and taste preferences. An intelligent digital procedure imports these preferences into a computational tool before preparing the meals, and thus proposes a new paradigm for human-computer interaction in cooking. Specifically, their parametric generated CAD model will determine the exact distribution of ingredients to meet customers' individual preferences, as well as a distribution model, both of which are determined by chefs when planning dishes and their hybird recipes.

Figure 2.1 Hybrid kitchen

In conclusion, they claimed that the Digital Gastronomy Cooking Portfolio will push the development of hybrids cooking methods in the kitchen, complement modernist cooking and maintain traditional food cultures alongside innovation and opportunities, and provide a field with diversity for the future development of ideas and food experiences.

2.1.2 3D Printed Sushi for Nursing Foods

Research at Yamagata University is currently studying models of nursing foods for the elderly. According to a interview,[2]. Professor Katsutoshi Kawakami mentioned that long-term nursing food is an area that is being developed into practical application at the commercial level. They are collaborating with food manufacturers to do further research and development in the current stage. Traditional long-term used nursing foods are mostly paste-like, which makes it difficult to obtain an appetizing taste and appearance. That is where 3D food printers come in. For example, in a salmon dish, you can fill different materials and ingredients in two extruders to make a salty "grilled salmon" with a soft flesh and slightly firm skin. This can reproduce not only the appearance, but also the flavor and texture changes, then make the texture more chewy. In addition to being delicious, it also helps to inhibit the decline of chewing and swallowing ability in the elderly.

On the other hand, if someone would like to use a 3D food printer to make nursing food, they are able to customize the food to matches with the individuals' requirement and produce a well nutrition balance dish as quick as possible. [9]Therefore, the burden on caregivers can be significantly reduced. In addition, we can even combine hard and soft ingredients to create dishes with rich textures and fresh flavors. The biggest feature is that it provides "customized food" for the enjoyment of long-term caregivers. It is not only psychologically gratifying for the elderly and caregivers, but also offer a physically rewarding as they are able to chew food with their mouths and eat what they want. The following picture below shows some 3d printed sushi made by Professor Katsutoshi Kawakami.(Fig:**??**[3]).

Currently, Professor Katsutoshi Kawakami is preparing for an exhibition on the

2 https://cuisine-kingdom.com/3d-food-printer

3 https://cuisine-kingdom.com/3d-food-printer

future of food using 3D food printers at the Osaka Expo 2025. They considered that expanding the variety of 3D printed food and developing a 'Future Restaurant' rather than being used solely for long-term nursing food.Furthermore, in addition to some universities, many public and private sectors are exploring 3D food print technology as well. Some of them are even associate the idea with science fiction movie scenes, such as 3D food printers that convert the taste and shape of sushi into data and send it to a remote location. According to his interview, [4].he mentioned: If the evolution of 3D food printers continues as the current speed, and at a low price, the era of the "family" could be upon us soon.

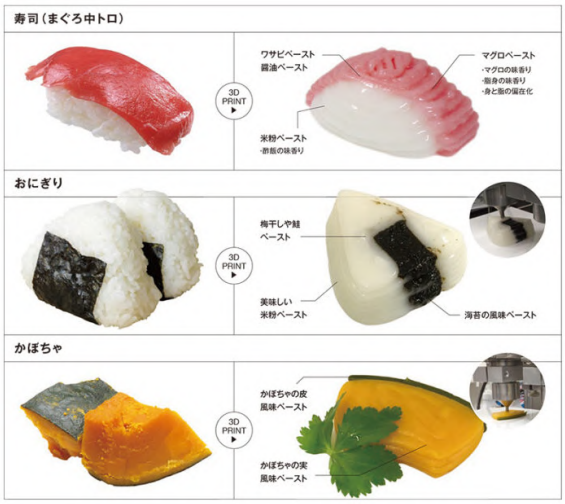


Figure 2.2 3d Printed Sushi by Yamagata University

2.1.3 Providing a Positive Dining Experience Towards Picky Eaters

Most Often, the longer a person avoids tasting new foods, the more picky they will become. The eating habits we develop during childhood and cognition with food are critical to the way people eat after they become a adult. Recent research has shown that food neophobia is actually a heritable trait. [10]

4 https://blogs.ricoh.co.jp/RISB/environment/post_690.html

Basically, parents can transfer on the "picky" gene to their children, making some of them more prone to pickiness than others. Additionally, children or younger generations often have more sensitive tastes than adults, because of more taste buds they have. In the process of gradually growing up, they lose them. [5].Most importantly, there are genetic differences in our actual taste buds themselves. Moreover, it is significant to know that certain food tastes are different to all of us. But for an adult picky eater, it is still very possible to broaden their food horizons by using the suitable picky eating strategies.

Sometimes, whether people are attempting to feed a picky eater or they are one of the picky eaters, mealtimes can be incredibly frustrating and often feeling stressful. However, for the majority, positive food experiences are usually different and unique. A positive food experience is not only about eating just to eat. It is about experiencing it, enjoying it, and creating memories. The approach to creating nutritious and delicious food, as well as the different dining environments, are all able to affect the dining experience. So that, cooking process is no less important to the food experience than meal presentation and eating.

There are some different factors to a positive dining experience. Different food reactions of people is part of the experience as well. Michelle Seidling, PhD, a well-known food experience architect and instructional psychologist, has said in her academic work describing food experiences that a positive food experience is a kind of memory. [10]It is something that people really enjoy, not just the food, but the atmosphere, the surrounding people and the interactions. How people make food. These components help to build a positive dining experience. Thus, eating favorite snack while watching TV would not be considered as a positive food experience because people focus on the show itself and not what they are eating. The food is provided just there for people to eat. For sure, food is not the core of the experience. And if the experience includes cooking, plating, tasting and interacting with friends and family while doing so, then food is more central to the food experience. It can be attributed to creating memories focused on the food (facilitated by and interacting with the food itself). This creates great memories.

5 https://www.positiveparentingsolutions.com/parenting/strategies-for-picky-eaters

Teaching and learning is an important part of a positive eating experience as well. For example, when people are currently struggling with a relatively complex or unfamiliar dish, an assisted lesson shared by a friend or app often helps them find a breakthrough. And while people complete an unprecedented challenge, the feeling that be bought from the success is often huge and impressive.

Positive dining experiences are about experiencing food and the components that be consisted from dining experience. Depending on age, maturity, environment and other influencing factors, positive food experiences are all different to each individual. [6].People tend to have more positive food experiences when they make their own food. People all have different experiences and different backgrounds that they can share with each other. Working with food is a positive food experience. It is at the core of our being: creating something exciting, something memorable, having the experience of working with it, preparing and cooking the food, and plating it. Food experiences are also spiritually stimulating. A positive food experience is one where food is the primary focus.

2.2. Related works

2.2.1 Case Study 1 :Lemon-box - Customized Vitamin

Vitamins are able be customized as well. Traditional health care products have been marked with the stereotype of "micro-business products". It is hard to imagine any other innovation in this industry. However, with market changes, customized vitamins and other nutritional supplements have given rise to a niche segment. To meet the needs of more "advanced" customization. It has to be admitted that health supplements, which receive a lot of criticism few years ago, are gradually entering the insights of young generation. Custom vitamins, custom health care plans, and customized foods are making huge waves in current stage. According to the statistics, health care companies are favored by capital.

For example, Care/of, a customized nutrition start-up company established in 2016, has completed financing valued US 82.9 million dollars. Hum Nutrition,

6 https://medium.com/@FoodExUnplugged/defining-a-positive-food-experience-progression-day-by-day-6d11d8e58b51

another nutritional supplement brand claimed they are adopting a personalized subscription mode and announced the completion of US 5 million dollars in Series A financing 5 years ago. Remise is a brand that offers users with customized services for well sleep. In 2019, it completed a seed round of financing of US 8.2 million dollars.Lemon box is another good example. Since the company was established from Silicon Valley, they collaborate with nutritionists and complete a purely transparent nutrition plan to all of their customers. So that any of the customer is able to learn their current health condition and missing nutrition by the professional questionnaires.

There is no doubt that young generations are becoming the main consumer in nowadays. For LemonBox, youthfulness is also the core concept of its company. For further details, LemonBox has a more clear classification of the young generations. They selected women aged 25-35 from the first to third-tier cities as its main target users.Focusing on these community, they have a certain level of consuming ability and have greater health requirements than the others.[7].According to busy work, heavy pressure and some other reasons, they lack the time and energy to understand and study their own physical health conditions and suitable nutrition supplements.Meanwhile, the customized "convenience" of LemonBox and the "high quality" imported from the United States and recommended by senior nutritionists just match their needs.In fact, LemonBox has completed a brand upgrade in the second half of 2020, transforming the originally younger target group into the current customer group. From logo to packaging, LemonBox has changed the previous cute style, and mainly focusing on the simplicity, which is more suitable for the aesthetics of white-collar ladies.

Moreover, LemonBox is not only a health product consumer company. From the very beginning, LemonBox has positioned itself as a technology company that driven by data-driven algorithms. In 2018, LemonBox formed an algorithm technology team, which occupied 1/5 of the company's total employees, and also built a team of purely nutritionists. The nutritionists charged in constructing a giant nutrition knowledge diagram, (in application forms) and the AI algorithm matches user data with the knowledge diagram to intelligently recommend suitable

7 https://inf.news/en/economy/e4c89b2266925163c8a213e90120d512.html

Figure 2.3 Lemonbox Package Design

vitamins and nutrition for their users. With the support of big data, the algorithm team also specially launched a "light customization series" suitable for common symptoms for target groups who are unwilling to fill in the questionnaire, such as a combination of vitamin B to relieve fatigue, and a combination of grape seed and melatonin to promote sleep and beauty. The sense of technology and professionalism brought by Lemonbox is undoubtedly a significant factor for young consumers to gradually trust a new brand.

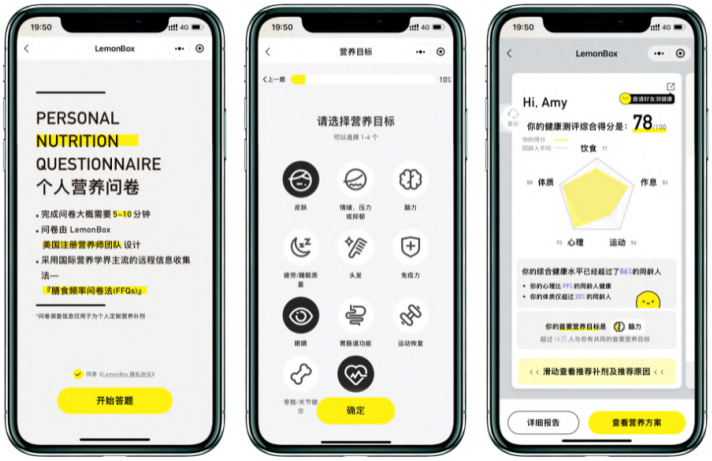


Figure 2.4 Nutrition Knowledge Diagram in APP Forms

2.2.2 Case Studies 2: Customized 3d Printed Dessert

Three MIT students have developed a modified 3D food printer which are able to manufacture customized ice cream in different shapes, and if the process is worked successfully users would have their customized desserts to order in the near future. The usage of a Solidoodle printer and a Cuisinart soft-serve ice cream machine in that team was able to complete the food print within a self-imposed 15-minute window.To sustain the low temperature of the ice cream and in shape, the 3D printer was arranged inside of the tiny freezer, while the printed materials was mixed with different ingredients of food and sprayed with a liquid nitrogen solution. After several times less-than-impressive prototype, the setup eventually printed a dessert into a star-shape and they deduce that 3d printed dessert might one day appear on a restaurant menu.

Figure 2.5 Star-shaped 3d Printed Ice Cream

According to the interview of the team, [8].they said "We were inspired to design this printer because we wanted to make something fun with this up-and-coming technology in a way that we could grab the attention of kids," Kristine Bunker told TechCrunch. "We felt that it was just as important to come up with a new technology as it was to interest the younger generation in pursuing science and technology so we can continue pushing the limits of what is possible." Lots of

8 https://www.digitaltrends.com/cool-tech/ice-cream-next-3d-printed-food-menu

different foods and dishes have already been made with the experimental 3D food printers. Fruit, pizzas, sweets and several other edible objects have been produced as printers get more intelligent and more cost-effective, though these projects still require further works in progress. Furthermore, unlike most regular food printing technologies that require reprocessing (usually heating) after printing to be safe for users to eat, this project demonstrates that 3d printing technology can also be applied to the food in low-temperature.

One Ukrainian chef, Dinara Kasko, reveals how she has created herself a different perspective with her dessert creations by adopting the 3D food printing technology. The 29-year-old woman has been a pastry chef for almost two years and has recently attempted to create her desserts using a 3D printer. Speaking to Goodman Fielder Food Service,[9]. Dinara explained her "concept is to create cakes that are just the design objects. When people firstly have a glance on them, it is uncertain to them if it is something edible. she like that," from the Financial Review. In addition, Dinara claimed that she first used the technology just because she wanted to create a mold with her own featured design, so she used 3D printing technology in the process. Once the mold solidified, the pastry chef explained, she cast it with a silicone coating and then filled it with the ingredients for the dessert, which was then frozen until it solidified.While the mixture has become solid, she immediately take the cake out of the mould and then decorates them by using her unique style and bright colors. Many of her innovated designs have been completed with a flawless glaze or velour.(Fig:**??**[10]).

Since the 3D printer has became a necessary part of her kitchen, Dinara has admitted that she was appreciate to her job because of the multi-possibilities of new discovery. "This technology makes dessert easier and also more complicated at the same time. If people start to use it, they will set up more challenging goals naturally in order to get people surprised," she explained."Decide whether it will be a one-time experiment or whether people would like to work with it on a regular basis, uers need to have a clear understanding of why they need it and how to use it... is it aim to create surprised shapes or just to adopt it as one

9 https://www.gffoodservice.com.au/idea/chef-masters-dessert-with-3d-printer

10 https://www.gffoodservice.com.au/idea/chef-masters-dessert-with-3d-printer

pleasant dining experience, set yourself apart from the others? Never be afraid to experiment."

Figure 2.6 3d Printed Cakes

Figure 2.7 Design Mould Sample

2.3. Summary of Related Works

After reading and understanding the previous articles, we then summarized our findings into the following solutions. From the technical perspective of 3d printing technology, we found that 3d printing technology can be applied to the printing of

materials in low temperature. 3d printing technology allows precise control of food mixing ratios and geometric shapes. And if parametric design tools are imported into cooking, chefs are able to freely customize the taste, flavor, structure and aesthetics of their dishes on their preference.

In addition, in the 3d printing application level, we found that the current demand for nutritional supplement products from the young generations are in a increasing trend while the convenience of using nutritional products and good quality are important influencing factors to stand out in the current market within numerous nutritional supplements products. And based on the analysis of 3d printing technology above, we can understand the fact that by using 3d food printers, it is possible to produce a well nutrition balanced dishes according to the individual requirements of various users. Meanwhile, the different dining experience brought by 3d printing technology is now being developed and adopted by a huge majority of restaurants, food processors and other organizations to bring a positive dining experience to the users.

Moreover, due to the utilization of dining experience, positive food experience is proven to be one of the effective methods for picky eaters. The surrounding environment and the interaction of the meal can directly affect the mood of the user's dining experience and even alter the awareness of different dishes. Teaching and learning is such one of the significant sections of this positive interaction.

Chapter 3
Design Progress

3.1. Overview

In this project, we will attempt to utilize 3D food printing technology to customized nutritional intake. This will be a entire food customization service design. Users will have the opportunity to perform customized food printing in their daily living environment. In this chapter, we will first show the flow chart of the dining experience by using the designed food printing service, and then categorize the design sessions into two parts,which are software and hardware design.

We hope our participants to make nutritional supplementation as a daily habit. We will simplify what would otherwise be a relatively complex food printing process through an app, and enable the experience to be an enjoyable and pleasant dining experience with effective nutritional supplementation. In other words, it is significant to understand how to add playfulness to the dining experience without compromising its effectiveness.We will attempt to discover several methods or some influencing the factors that are able to affect users behaviors and the feeling of dining experience, such as:

- How to evoke positive feelings in the participants through an enjoyable dining experience.
- How to make the experience stick to use this customized service instead of giving it up and ignoring it like a usual nutritional supplement product.
- How to improve the eating habits of the participants through the service, so that achieving regular daily dietary.

3.2. Design Flow Chart

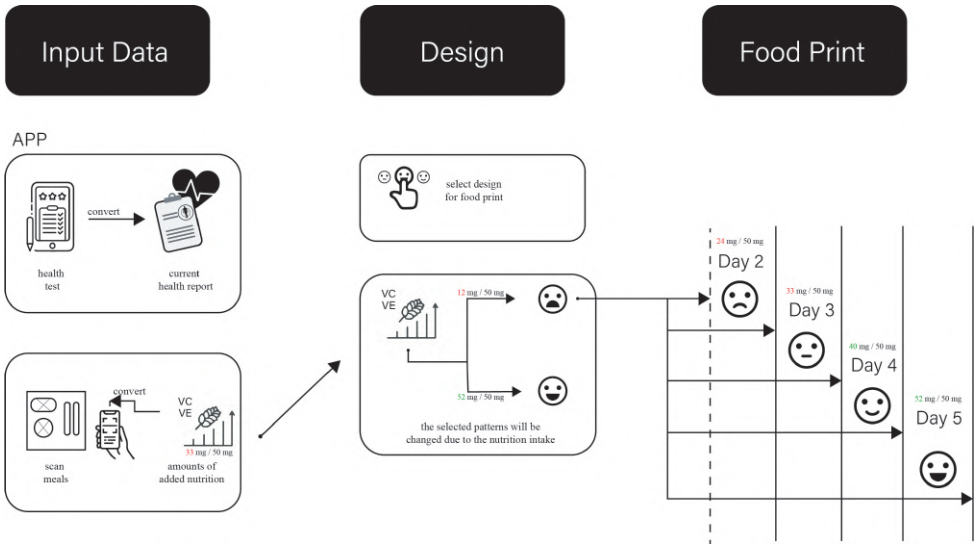


Figure 3.1 Design Flow Charts

From the above diagram, it is not hard to figure out that there are mainly three sections which are respectively input data, design and food printing. First of all, the input data includes the participant's current health data of and the specific amounts of nutrition they receive from their daily dietary. These are also essential to ensure that effective nutritional supplementation can take place. Participants will initially fill out a health questionnaire provided by the app [improved by Lemonbox] to analyze their current health status and set future health goals. Then, by scanning the total amount of nutrients from the dietary, the specific amount of nutrients that need to be supplemented will be calculated and analyzed through the App. (The daily nutritional standards required by users are mainly derived from: Japanese food standard composition table, kichintowakaru eiyoushyoku, and daily nutrient requirements calculator) [11] [12] This program will be more accurate and effective than ordinary nutritional supplementation products because those products do not provide intelligent nutritional supplementation requirement based on different dietary standards on a daily basis.

The design session includes a participant-specific customized design, in which the participants will first select their options of food printing they would like

to produce. The amount of missing nutrients calculated by the app will result into some geometric changes in the options has been chosen. We hope that kind of geometric changes will bring playfulness to participants. While participants continue to adjust their daily dietary, the food printouts will also be changed each day. In section 3, we show a schematic diagram of food prints with different geometric variables generated by different nutritional parameters. In other words, depending on the nutritional content of the readjusted diet, the food print objects will be positively or negatively affected. We believe that those geometric variables of the food print will cause visual and perceptive effects on the participants, leading to changes in their feelings. This will make the participants to try hard to achieve the perfect food print before printing it. Thus, the goal is to get them to persistently adjust their daily diet in order to achieve the food print as their desire.

3.3. Design Methodology: - Reasons for using 3D Food Print and Its Novelty

3D food printing provides a extremely wide diversity of usable, fully customized foods that fit exactly the needs, tastes of different community by adapting the composition, density, structure, colors to user preferences and requirements. [13]As one of the most representative automatic food processing technologies, food 3D printers are currently focused on improving the artistic quality of food in the short term and the health of consumers in the long term. Compared with traditional cooking methods, 3D food printing is able to adjust the texture of food by adjusting the composition and layering the print. [14]According to the researches, 3D food printing has beneficial effects on human health as well. For example, it can effectively help human avoid the spread of food-borne illnesses and eliminate sources of disease, while allowing for easy integration of consumer data. [15] [6]It also allows for detailed design of food products using software tools and other digital methods. By using software tools and other tools, dishes can be designed in detail and create shapes that can not be created by ordinary cooking. [16] [17]And these effects are the main reasons why we have chosen food printing as a research tool in this project.

In this project, we will further utilize 3D food printing technology, which is currently widely used in the experimental stage, to figure out how to use it in a more convenient way through the different daily scenes. Additionally, we will explore the possibilities of 3d food technology in nutritional balance, through customized editing printing service system to improve the eating experience of 3d printer technology while obtaining effective nutritional supplements. It mainly consisted by the improvement and design of the next 3d food printing technology on either the hardware and the software. Moreover, we hope that 3d printers are not only used for people to be able to eat consistent quality food in their lives, but also to effectively allow them to adhere to change their dietary and eating habits so that to naturally improve their nutritional deficiencies.

3.4. Software Design

3.4.1 UI Design

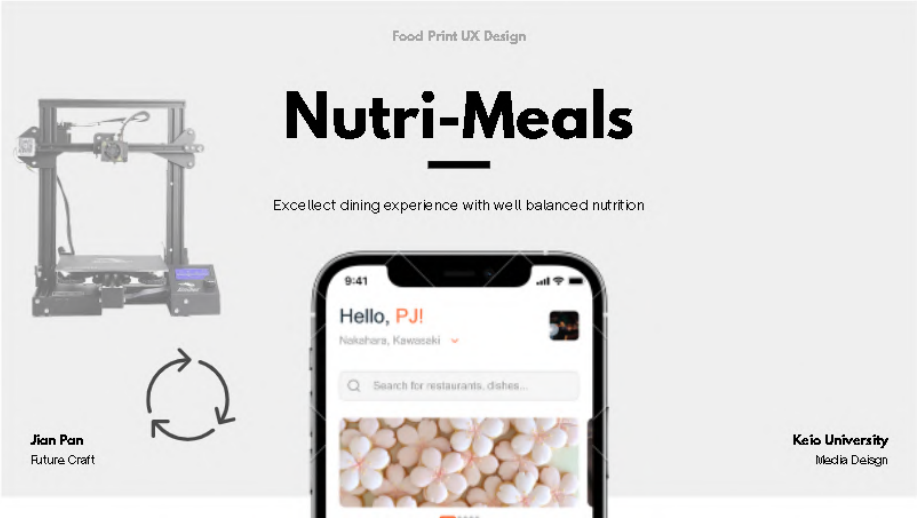


Figure 3.2 NutriMeals App

"NutriMeals", this app was initially designed for simplify the 3d food printing processes and enhance the users dining experience. As the above diagram shows,

'NutriMeals' collaborate with 'Creality 3D Ender 3' [1]. which is originally a 3d printer and remodeling by us to use as a 3d food printer. In our vision, we want to enable users who have negative emotions about nutritional supplements products to change their original negative attitudes as a positive emotion by experiencing more convenient and playful functions from the App. Based on the preliminary researches, (Chapter 2.2.1)we set the main colors of the app in bright and light color tones that match aesthetics of young ladies. Icons and system texts were also designed in a cute and neat style.

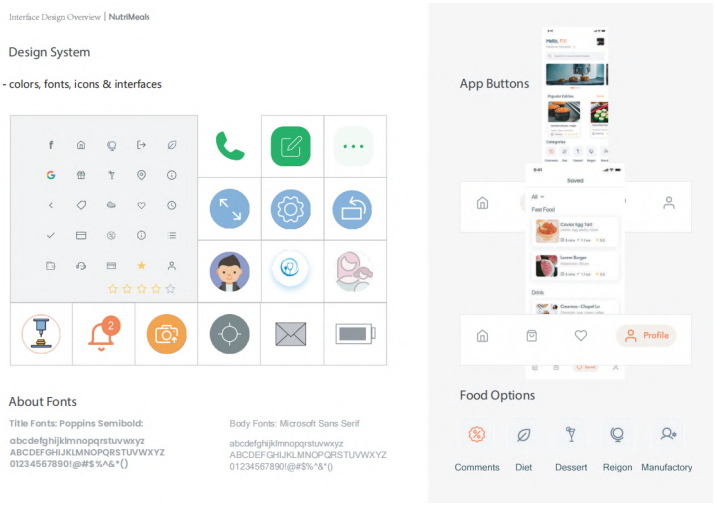


Figure 3.3 System Interface Design

As a result of using the custom food printing service for a period of time, we expect that users will be motivated to insist to do the nutrition intake everyday and pay attention to their daily dietary, thus creating long-term good health habits. Roughly, 'NutriMeals' have four basic functions:

- Health Management: 'NutriMeals' provides a visible and Real-time data through users physical health data.
- Food Customization: 'NutriMeals' is able to adjust food hardness, sugar amounts and infill nutrition. It also leads to geometric variables according to the amounts of daily nutrition intake.

1 `https://www.creality.com/products/ender-3-3d-printer`

- Intelligent Instructions: We developed instruction functions through the 'NutriMeals' to simplify the complex 3d food print process and provide professional advice to users daily dietary.
- Health Support Services: As some additional functions, users will have opportunities to use 'NutriMeals' to purchase food print materials and make reservation some medical support services.

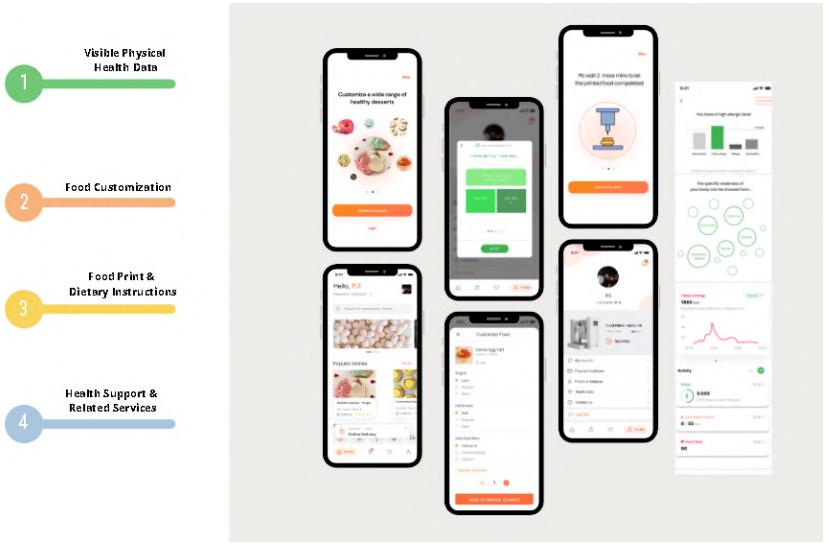


Figure 3.4 NutriMeals Functions

3.4.2 UX Design

During the ux design process, we considered that users suffer from chronic malnutrition mainly because of their inability of long-termly adhere to nutrition balance, and their resistance to nutritional pharmaceuticals. In other words, taking nutritional supplements is often perceived by people as the same behavior as taking medicine, and thus they think their own health status is fine even if they do not take them.In addition, the singularly joyless eating experience brought by nutritional supplements based on the busy lifestyle (work or study) often leads them to be eventually forgotten in an obscure corner. Therefore, we intend to propose a method to convert users' attitude towards nutritional supplements by providing

them with a playful and enjoyable eating experience through 3d food printing technology. According to the researches from Pilska M and Nesterowicz, sometimes negative emotions will lead us to reach for dessert and sweat snacks, which are the easiest and convienient method to cause psychological discomfort decrease or provide some sort of stimulation of distracting human's attention. [18]And that is why we eventually selected dessert as our main materials for the customized food print. We deduce that with enthusiasm for this service, users will eventually make supplementation a daily habit.

The figure below shows specifically one of the food customization functions that we have developed to improve users' dining experience. Unlike the customization of foodprint materials that introduced in the last chapter (from 3.4.1), the effect of this customization function can be considered primarily as a sort of geometric variable. Users will use the dietary scanning function of 'NutriMeals' to calculate the exact value of their daily nutritional intake. Then, depending on the daily nutrition goal has been set from the very beginning, the final print objects of users' choice will be rewarded or punished accordingly to the previous data (sufficient or insufficient nutrition intake). This feature was developed by using rhino and grasshopper jointly. For example, the expression of Pikachu in the image below (as one of the examples) will be changed according to the value of nutrition intake for that day. If the value for the day is reached or exceeded, the expression will remain the same or shift to a positive emotion to tell the user that the day's mission has been accomplished. Conversely, if the user falls far below the pre-set value for the day, the system will make Pikachu's expression become a negative emotion (annoyed, bitter, etc.) to motivate the user to adjust the dietary and fulfill the nutritional balance in the following days.

3.5. Hardware Design

Nowadays, the vast majority of the 3D food printing processes requires a single processing step to transform the material into its final form (Wegrzyn, Golding, Archer, 2012). [19] [20]3D food printing closely duplicates the process in non-food-based 3D printing. While this analogy is a useful feature from the perspective of print process adoption, it makes 3D printing difficult to integrate into the kitchen

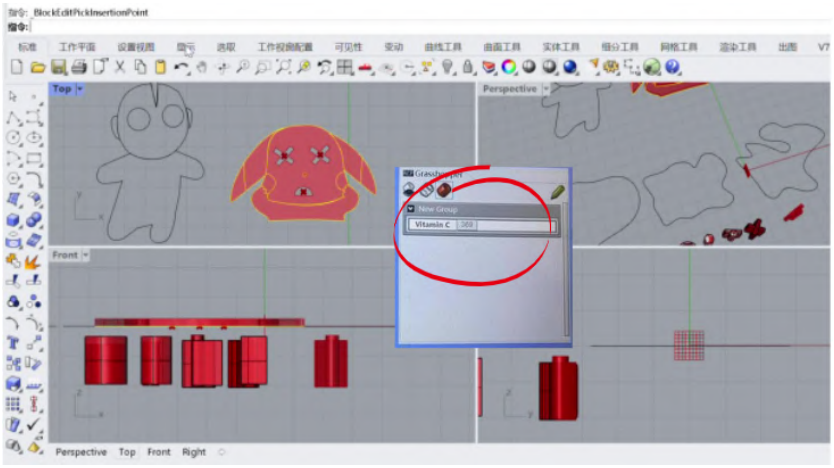


Figure 3.5 UX Design Sample

or industrial-scale production. Furthermore, the figure below [2].shows in detail that two 3D printers are widely used for commercial purposes and the technology of extruding food materials through the nozzles of the vast majority of 3d food printers at current stage. [21] In this project, we firstly re-equip the 3d printer "Creality 3D Ender 3" to a food printer. Then, we develop some conceptual design of equipping greater extruders to separate materials for future diverse printing. However, its is still in the experimental stage. Thus, the specific re-equipment process and conceptual design will be illustrated in detail below.

3.5.1 Installation and Re-equipment

In the process of redesigning and assembling the 3d printer "Creality 3D Ender 3", we retained the main frame parts of the original printer (platform, display, monitor, etc.) and equipped them at the very beginning by follow the instructions from product manual. (Process-1) This gave us a more in-depth comprehension of the composition of the 3d printer.

On the other hand, since most of the current food printers use syringes as print extruders, we re-designed and assembled the support accessories for the print extruders by using the laser cutting machine (Process-2). This also ensured that

2 https://www.creality.com/products/ender-3-3d-printer

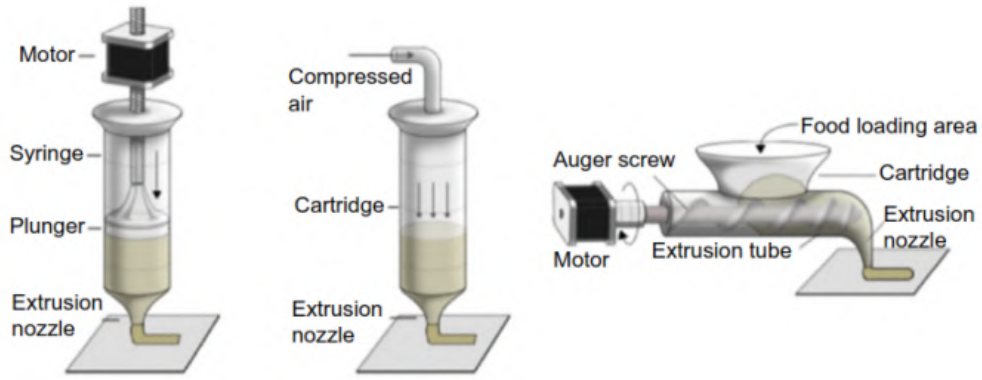
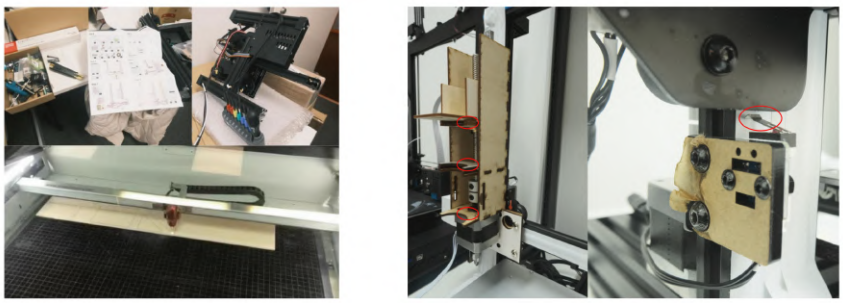


Figure 3.6 Extrusion Mechanisms

the raw materials could be filled sufficiently and also exhausted the inside air to reduce the loss of the printed model. In addition, in order to match with the new extruders, we redesigned the measuring parts for adjusting the print level. (Process-2)It mainly consists by an acrylic plate, a spring plate and a roller shaft and be designed to empower users in real time to avoid the undesirable printing results that caused by changed extrusion multiplier and fill density values due to different printing materials.



Process-1 Process-2

Figure 3.7 Processes

3.5.2 The Conceptual Design

Furthermore, we are attempting to develop food printers that are capable of performing multi-head food printing. As the diagram has shown below, we expect that in the future we will be able to use only one printer for multiple printouts of a single print object as the extruders will be set in different sequences. In other words, the three extruders in the diagram below will sequentially execute their respective print tasks. One extruder will automatically rise when it completes its current print tasks, while another print extruder will lower to a level with the current print objects at the same time to continue the following printing.

As we could figure out from the following diagram , multiple extruders will be able to customize their individual data. We believe that this will greatly simplify the complexity of adjusting the system data due to the different print materials. It would also allow the print objects themselves to have multiple ingredients and different textures to improve the higher nutritional value either the higher artistic appeal. However, according to this concept is still in the experimental stage, there is some instability existed and we are still gradually developing it.

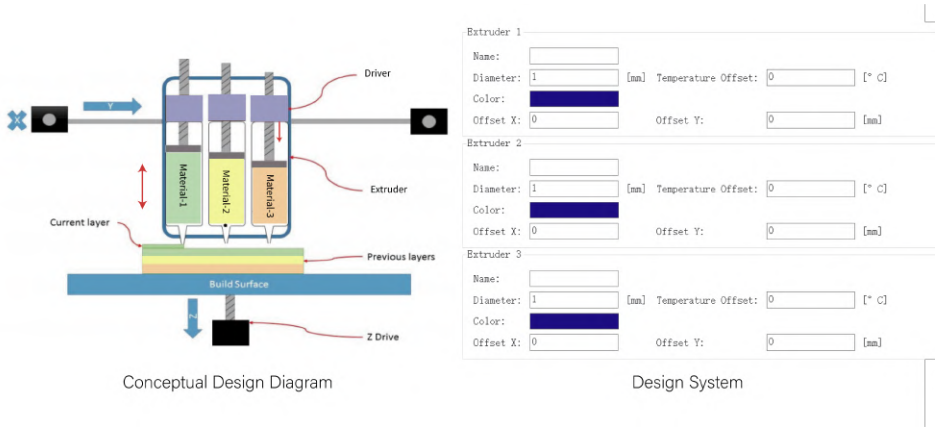


Figure 3.8 Conceptual Designs

Chapter 4
Customized Food Print Prototypes

4.1. Overview

Prototype Proposal Form			
No.	Key Points	Contents	Goal
1	Dfferent Materials	Cream and Surimi Powder	Finding the including factors between the foodprint and different materials
2	Geometric Possibilities	2D and 3D Food Print	Finding the feasibility between customized 2D and 3D formed Food Print
3	Color-Change Food Print	3D Food Print with Multiple Food Pigment	Attempting to make colorful food print
4	Nutrition Tastes	The Mixture with Raw Materials & Vitamins	Attempting to use vitamins to adjust the taste of raw materials

Figure 4.1 Prototype Proposal Form

In this chapter, it mainly chronicles the technical prototype processes of 3d food printing. To classify our aim, We were wondering to determine the influencing factors of 3d food printing based on different experiments, which will lead to the simplification of 3d food printing. In addition, based on the research questions mentioned in the previous chapter, we also attempt to validate them through an updated research progress. The specific details are able to be shown in the figure above.

So that, we roughly set 5 different tasks to do the prototypes,which are respectively: materials, 2D 3D customized design, color-changed food print, customized nutritional food print, vitamin tastes changes.

4.2. Prototype 1 - Materials

During the prototype test, we attempted to determine the influencing factors of different materials on 3d food printing. Since 3d food printing is usually limited by the material hardness, we mainly selected the soft materials. In this section, 3d food printing processes on the material will be measured respectively by surimi powder and different creams (peanut, chocolate, custard).

First, we used the surimi powder developed by suzushiro, [1]. a miracle powder that can be used to make fish meal by mixing with water and heating. In this experiment, I attempt to print food with different humidity and volume of food materials in order to verify the effect of different humidity and volume on the print. As shown in the following picture, the surimi powder is a solid pack of powdered material that gradually thickens by mixing with different proportions of water to become like a white paste-like material in forms of solid-liquid mixture. In other words, before it has been added to the food printing extruder, we still need a re-processing step to adjust the material moisture. In this prototype test, we used different ratios of water and surimi powder for fusion (3 to 1, 4 to 1 and 5 to 1).

Figure 4.2 Surimi Powder Preparation

As a result, it shows that surimi powder requires a relatively large amount of water for mixing when being used for food print. And 4 to 1 had been proved as the minimum requirement. While ratios lower than this, it will become extremely

1 https://www.kamaboko.com/surimipowder/

dry and not able to use for regular food prints. Thus, 5 to 1 mixing of water with surimi powder is the most ideal mixing ratio. Due to the high absorption of the surimi powder itself has, although 4 to 1 mixing ratio had been proved to be able to print, but after 20 minutes of resting, it will still gradually become dry and thus enhance the material softness and eventually cause food printing loss. The figure below shows the surimi pyramid printed at a 5 to 1 of mix ratio. Moreover, according to the surimi powder can not be eaten directly, it still needs to be heated in the oven before users eat it after the food printing process. After heating, the material itself changes to a softer and more elastic solid form. It will be able to squeeze and deform by using chopsticks, while the inside structure is a semi-hollow and granular state.

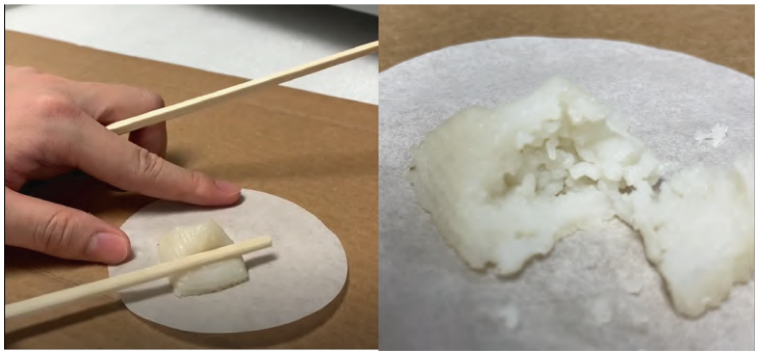


Figure 4.3 Food Print Pyramid

Moreover, according to the surimi powder can not be eaten directly, it still needs to be heated in the oven before users eat it after the food printing process. After heating, the material itself changes to a softer and more elastic solid form. It will be able to squeeze and deform by using chopsticks, while the inside structure is a semi-hollow and granular state.

Additionally, we used different flavors of cream in the second material prototype test. (peanut, chocolate, custard) Compare with the previous material, they did not have to be reprocessed before using to do food print. During the prototyping processes, the consistency and softness of different cream were verified by multiple food printing sessions as a material that is ideal for food printing. After food printing completed, it does not require to be heated and then to be consumed as well. According to research, [22] [23]the heating step often causes the evaporation

of water from the food itself, that resulting in the loss of inside nutrients.

In contrast, cream is usually able to be consumed directly, such as spreads it on the bread senbei and etc. On the other hands, freeze it and then have them is also a good option. The picture below shows a scene where the creme is covered with senbei through food printing. Studies have shown that [2]. when refrigerated, the loss of nutrients is almost negligible compared to the amount lost during heating. Refrigeration also tends to make creme abundant in taste. Therefore, creme was used extensively in our subsequent prototype and user testing.

Figure 4.4 Food Print Creme on Senbei

4.3. Prototype 2 - 2D 3D Food Print

For the second prototype, we intend to examine the effect of geometric complexity on the food prints. During the prototype testing process, we designed multiple food print objects by modeling software (usually in solidworks and rhino) which were mainly classified into two forms: 2d and 3d foodprint. Based on the similarity between food printing and 3d printing, food printing is also usually adopted as a layer-by-layer printing mode. The results show that most 3d food printing techniques require a certain amount of hardness in raw materials, otherwise it would result in the print outcome not being able to stack upwards during the

2 https://nutritiondata.self.com/topics/processing

printing process.(shown in the figure below)

Figure 4.5 Failed 3D Food Print

Although the hardness of the raw material itself did create a certain obstacle for food printing, we finally complete a series of 3d food printing by adjusting the extrusion multiplier as well as the fill density in the food printing options by multiple experiments. In addition, according to some of the 3d food printing objects have the problem of low precision and inability to complete complex patterns and textures, we think these problems might cause some troubles to the customized food printing service during the dining experience, so we did several prototypes on 2d food printing as well.

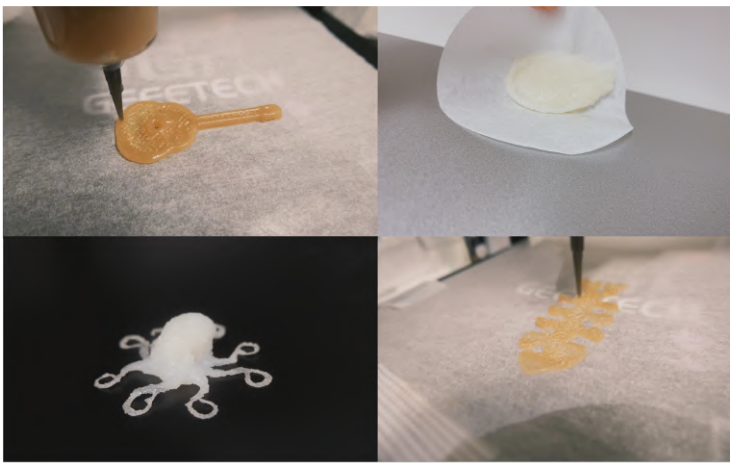


Figure 4.6 3D Food Print Samples

2D shaped food printing receive a higher quality than 3D food printing. Due to the reasons of thickness for 2d printing itself is much lower than that required for 3d printing, fewer layers will be resulted in increasing the geometric complexity of the printed outcome. In other words, 2d food printing can lead to more complex printouts in multi-curve and multi-surfaces. During the prototype, we firstly accomplished with some simple customized letter prints(Keio Media Design's Capital Letter), and then followed by a numerous patterns and flat models. Most of them were from existing anime and game characters as well as some objects from in human's daily life. As a result, either of them eventually reaped a high completion level.

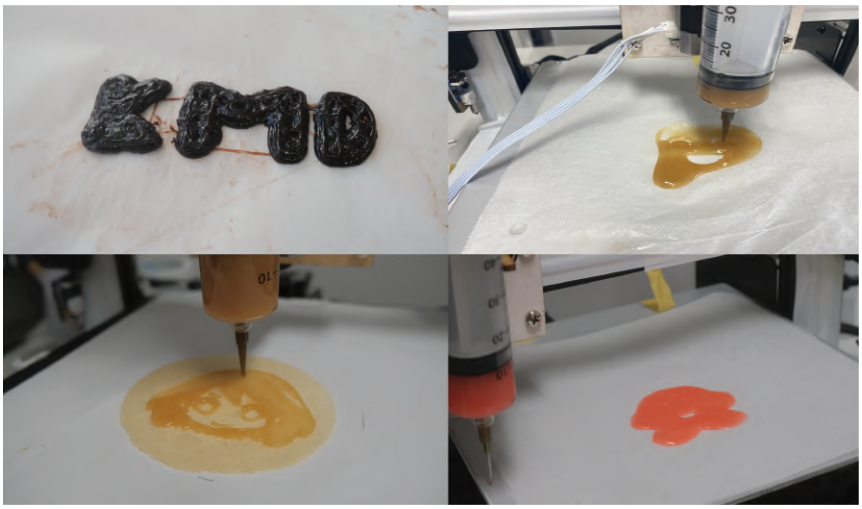


Figure 4.7 2D Food Print Samples

4.4. Prototype 3 - Food Print in Multi-colors

In the third prototype test, we intend to achieve a multi-color food print. Very similar to the previous prototype(2D and 3D Food Print), the application of multiple colors was also related to the softness of the raw material. During the first test, we used a relatively soft surimi mixture (surimi powder and water) and then made the food print by adding some sort of edible pigments. As can be seen in the figure below, the two different colors of surimi mixture were added to same

extruder and gradually mixed together during the food printing process. The final printout also illustrate a state of color mixing. In other words, the colours were not printed separately.

Figure 4.8 Multi-colour Print 1

Therefore, we also develop a second food print using flour mixed with butter and followed up with the same procedure (adding food coloring). The picture below shows the final product in detail. It is not hard to see that due to the increased hardness of the raw material, the different colors were well separated and resulting in a multi-colored food print.

Figure 4.9 Multi-colour Print 2

4.5. Prototype 4 - Vitamin Taste Change

For the fourth prototype test, we selected a variety of vitamins and then mixed them with the raw materials for food print and then test whether the flavour of the final printouts could be altered by adding vitamins or not. The specific purpose of this prototype is to understand the taste properties of multiple vitamins which are nutritionally significant for the maintenance of human life as well.

For the testing session, we purchased two different vitamin products that manufactured by DHC company in advance.(Viatmin C and E)[3].They are usually in the form of tablet as well as pills. According to the Susan S. Schifman's studies of nutrients tastes, [24]we then tried to imagine a future scenario of customized food printing by mixing 150 grams of custard with 50 milligram of different vitamins separately. Totally, we invite 10 person to do the taste experiment. The specific results are shown in the space below.

- Vitamin E: It has a very weak, stale taste which has a fairly dry quality to itself. Uniformly, it was not judged to other tastessweet. sour. salty. or bitter It is not particularly good or bad. Half the subjects found that it had a sort of weak taste, while the other half tended to judge it more tasteless.

- Vitamin C: It has a clear, strong sour flavour under normal circumstances. However, due to the inherent sugar content of the raw material from food printing requirement, the results show that a minimum ratio of 4 to 1 is required to perceive the sourness. However, in the case of customized food prints, the amount we usually require per day does not achieve this standard.

3 https://www.dhc.co.jp/goods/catop02.jsp?sc_iid=common_header_catop02

Chapter 5
User Test Process

5.1. Overview

In recent years, most of the younger generation often suffer from malnutrition as a result of their busy working task and daily lives. In order to improve the immunity, the majority often purchase health supplements based on their individual health reports. However, most people are unable to take supplements regularly due to their busy schedules, or they are internally resistant to take them due to the numerous categories. This results in a large proportion of them spending a relatively large amount of money spending on nutritional supplements with little or even no effect. In this chapter, we conduct a user test to determine whether our proposed customized food printing serviceDetails in Chapter 3 can make more people more proactive in their daily lives to do the nutrition intake and lead to balanced nutrition.

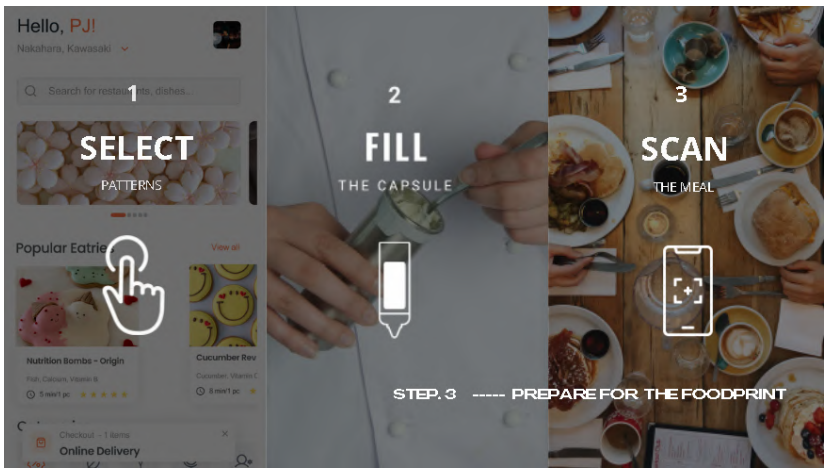


Figure 5.1 Customized Food Print Service

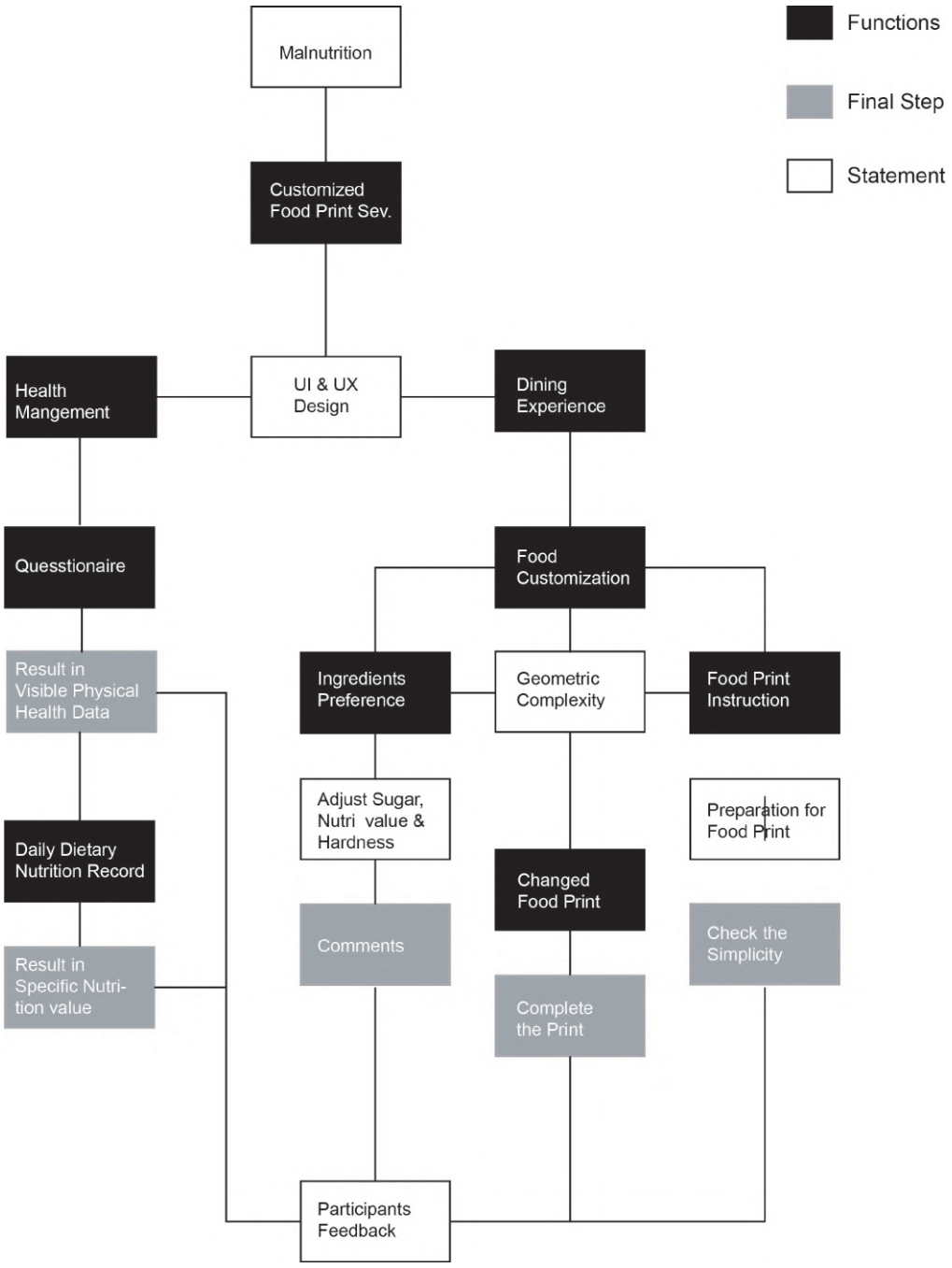


Figure 5.2 User Test Flow Chart

5.2. Flow Chart

In the diagram above, it documents the exact flow of our user testing processes. Based on the research questions and the hypotheses presented in Chapter 1.3.1 and 1.3.2, we expect to be able to validate them through user testing. Briefly, our objectives for this user test are concluded by the following (also available at grayed rectangle in the following diagram)

- Determine user satisfaction with the reports (visual data) generated by the health management questionnaire in the app.
- Determine user trust in the app's calculation of the user's daily nutrient requirements
- Determine user satisfaction with the simplified food printing process
- Determine user satisfaction with the food customization features (including geometric changes, food ingredients adjustment)
- Determine user satisfaction with the dining experience process
- Determine user's willingness to continue using the proposed customized food service

5.3. User selection criteria

According to the findings in Chapter 1.1.1 and 2.2.1, a large proportion of young women suffer from malnutrition and they also occupied a large amount of the consumption for nutritional supplements in the current market. Therefore, this user test focuses on young women aged 20-35 and gathered different insights into their customized health management system and the food printing process as well as their willingness to use this customized service. The total number of participants was 20, most of them were students and office workers. Moreover, the detailed age distribution is shown in the chart below.

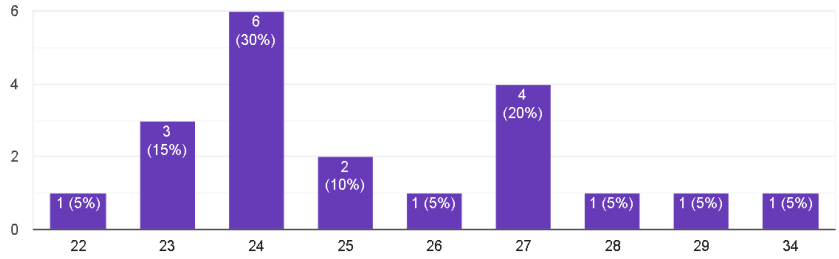


Figure 5.3 Age Distribution Chart

5.4. Evaluation Methodology

In order to maintain the integrity of the entire user experience process, we classified the whole experience process into two sections, input data analysis and the changeable models. The analysis of input data is mainly based on the user's different health levels and daily health goals, and the user's respective nutritional intake data would enter into the back-end database, which leads to changes in the following print model. We simulated the customization process that might be adopted by most users in the future, with detailed documentation of the user's customized health management and dining experience, respectively.

Participants will analyze the specific nutritional intake value by scanning the dietary of the day to calculate the amount of nutrients that need to be added to the customized food print. (The daily nutritional standards required by users are

mainly derived from: Japanese food standard composition table, kichintowakaru eiyoushyoku, and daily nutrient requirements calculator) [11] [12]The different standard nutritional amounts will then be compared to the health goals, thus altering the print model chosen by the participants. Currently, the user experience is mainly through the change of expression of the print model, which is shown in the figure below.

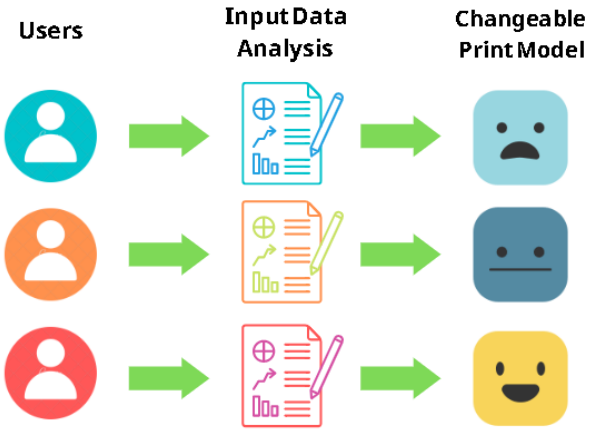


Figure 5.4 Evaluation Methodology Chart

5.5. Questionnaire Templates

In order to determine the user experience of involving the entire customized service food print processes, we then created a Google form to conduct a survey based on the previous questions in the flowchart session and received responses from 20 participants. During the user test, we combined app functions, user experience and desired future goals in order to gain feedback about the involved participants. Note: The included questions are be demonstrated in the appendix.(Roughly 2 sections: Health Management and Dining Experience, totally 26 questions)

1 https://docs.google.com/forms/d/e/1FAIpQLSeb2lknIO1ItHdeYzGP62J6-Lb2dSrLZbICaKnLXUZ1wTVB4A/viewform?usp=sf_link

Chapter 6
Evaluation

6.1. Overview

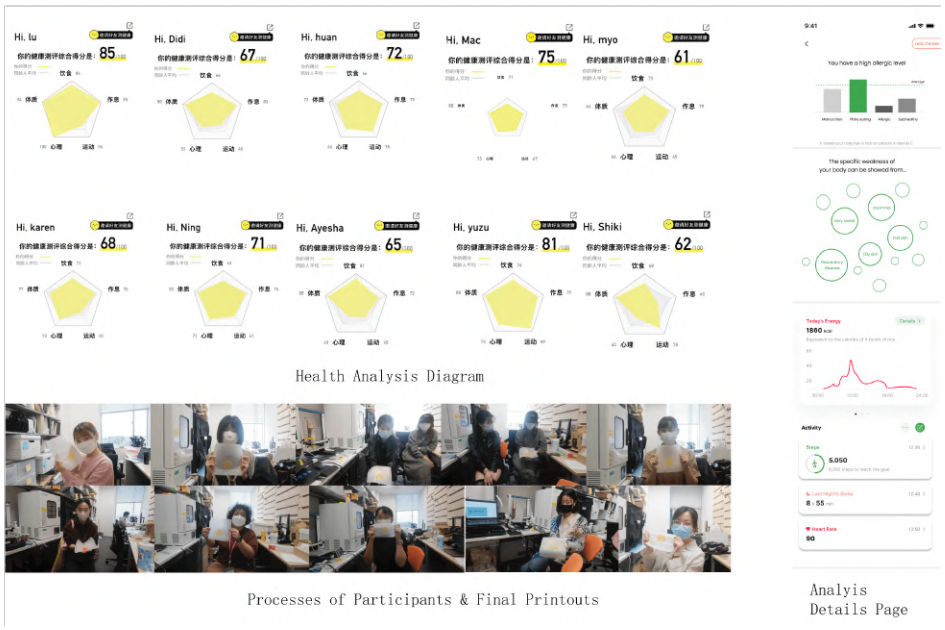


Figure 6.1 User Test Results

In this chapter, we expanded the data derived from previous user tests, analyzed through the three reference standards of nutritional intake, dietary experience, and the research questions and hypotheses presented in previous chapters. To make the result clear, some key data were selected for evaluation. (be shown in the diagram above)

Based on the individual scores generated by the health questionnaire for a total of 20 participants, we calculated a average score of 73.94 (out of 100). The

majority of the participants scored between 65-80, while the highest score was 85 and the lowest was 57. Unlike only 15% of the participants who had known 3d food printing beforehand, after receiving detailed health feedback produced from the app, approximately 90% of the respondents expressed a high willingness to continue using the service for nutrition balance. In the next session, we will further analyze and discuss the feedback and specific data from the user test in participants' nutrition intake and dining experience.

6.2. Nutrition Intake Analysis

In order to determine the professionalism and satisfaction of the nutrition intake effects, we generated a questionnaire to analyse participants' feeling after they completed the health management section from the previous flow chart.(Chapter 5.2) According to the result of the questionnaire, 75% of participants found the health questionnaire to be valuable and professional. Some of the participants also claimed that while users use this health management application, (especially for the health analysis graph) it has a sort of psychological effect which making users want to take nutrition intake after they saw it.

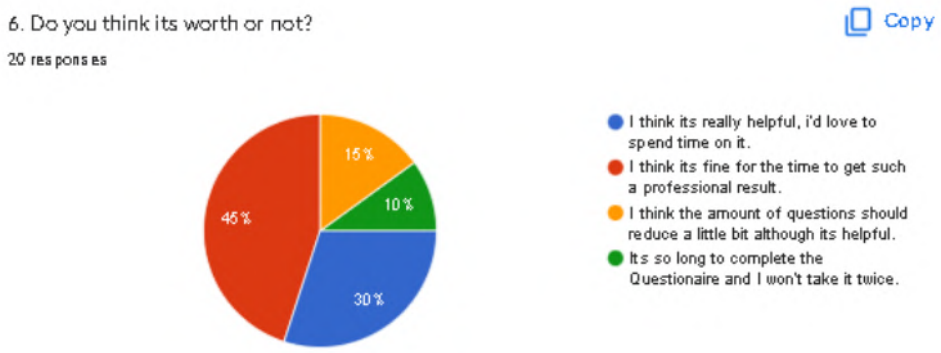


Figure 6.2 Health Function Satisfaction

In addition, the following graph is one of the examples from the multi- participants.We used a existed app - Karomiru, as our measurement tool. Participants only need to upload a photo of the their dietary for the day, the application will

analyse and then calculate the specific nutritional value by analyzing the taken photo. Therefore, on the right hand side, we can see that the vitamin C section is marked within red. Based on this data, the system was able to determine the exact amount of nutrients that the users needed to add to their customized food print.

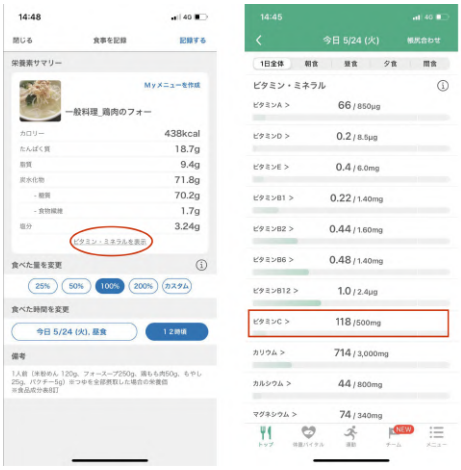


Figure 6.3 Nutrition Calculation Sample

Moreover, some of the participants mentioned that 'NutriMeals' still can be further adjusted. Roughly, these comments were mainly refers to the functions. They expect NutriMeals to provide users with a record of their nutritional intake history, as well as pushing regular reminders. Depending on the user's different requirements, NutriMeals as a customized nutrition management app is ought to add more customized versions for varied users (simplified, normal, professional versions). Besides, user privacy protection was also mentioned by the participants.

6.3. Dining Experience Analysis

Before conducting the test of participants' dining experience, we firstly evaluated the participants' cognition of the food printing technology. According to the results, only 15% of the participants had tried food printing before and 65% of participants claimed that they knew it but not really understood. In other words, most of the participants were not well informed about food printing technology.

However, after the participants had completed the entire food customization process, we gathered a great deal of positive feedback. As some examples, all of the participants felt satisfied with the final printout because it was designed by themselves and the process was pleasant and enjoyable. 85% of the participants were fond of the customization features, while 75% of them commented they would prefer to use the food printing service instead of taking supplements.

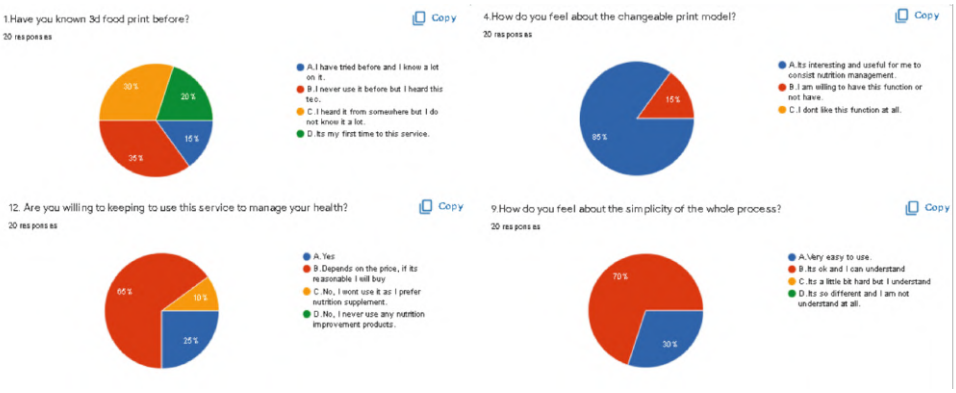


Figure 6.4 Customization Result

Additionally, we have also analyzed the research questions that were previously asked in Chapter One. Statistically, it reveals that almost everyone expressed an easy understanding of the simplified food printing process. For the dining experience, we adopted a form of recording the participants' mood variables and satisfaction that before and after the printout change.

The image below displays the customized food print models that participants eventfully gathered after the printing process. Due to the similar nutritional intake values from some participants and the selection of the same print template, 20 participants finalized 9 different food prints in total. Specifically, most users chose the Star Kirby as well as Mario print templates, and it is easy to figure out that all of them have a different expression respectively. In the second row of the image, it records the patterns drawn by the participants themselves (hearts, cats, slimes).

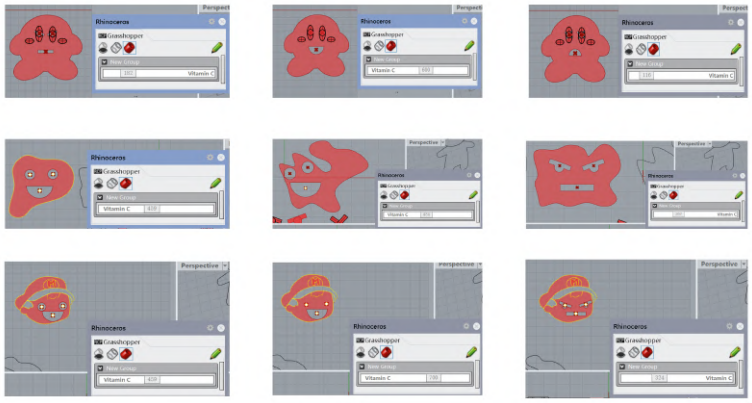


Figure 6.5 Changeable Print Models

Therefore, different values of nutritional intake generate different forms of Kirby. We then classified the specific transformed results into two situations, which were high nutrient intake and low nutrient intake.(During the user test session, the average nutritional intake standard was set at 250mg for different participants.)

6.3.1 Analysis of participants with low nutrient intake

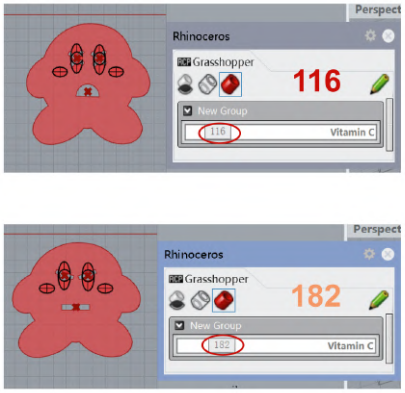


Figure 6.6 Low Nutrition Intake Model Change Samples

As a result, some of the participants gained a result that less than 150 mg of nutritional intake after analyzing their daily dietary through the app. This would

make Kirby (experimental sample) result into an chagrined expression, while a nutritional intake of 150-250 mg would lead to a depressed expression.(also be able to found in red figures like the above picture shows) According to their interviews, they claimed that they were able to feel a sort of depressed and regret feeling, and triggered their curiosity about the perfect print when they saw the negative emotional expression of Kirby.

For example, Ms. Fang is one of the participants who harvested feedback on a low nutritional intake. As we could easily found in the picture below, her lunch meals that day consisted with a fired pork with cabbage and a glass of orange soda. And while she received a sort of low nutritional intake score, she was surprised because she felt her lunch already contained with both vegetables and meat. "I had a feeling of frustration when I saw an unpleasant expression on Kirby's face." She responded in this way during the interview session. However, when she understood that the lower nutrition score was due to not eating food with the appropriate nutrition, she seemed a bit better. Meanwhile, when she saw that there were 5 different foods recommended in the app, she said she was willing to adjusting her dietary tomorrow because she wanted to see Kirby with a delightful smile. She also mentioned: Although she usually knows that she should eat more food according to her individual health goals, but she always gets easy to forget as various reasons, and either the changes in food print forms and the recommended food options through the app feedback have a reminder-like function and of course, if app can also have a alarm function in the next day as a might be more effective.

Figure 6.7 Lunch Recording with Low Nutrition Samples

6.3.2 Analysis of participants with high nutrient intake

On the other hand, when the target nutrient intake was higher than 250mg and lower than 500mg, Kirby would present a smile. When the participants exceeded the daily nutritional intake, the Kirby would be cheerful and continued laughing.

Furthermore, different from the previous participants with low nutritional intake, some of participants mentioned that they actually paid special attention to the dietary management to achieve a higher score today. And it would be difficult to maintain such an nutrition intake standard in their daily life. However, once they have achieved a high score just like this time did, they would certainly be delighted and fulfilled.

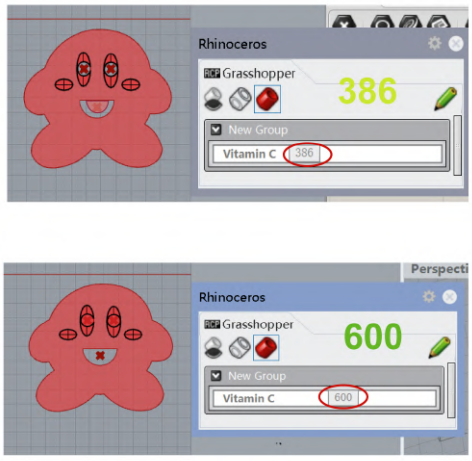


Figure 6.8 High Nutrition Intake Model Change Samples

6.3.3 Result Summary

Figure 6.9 User Test Process Works

At the end of the questionnaire research, participants were also asked about the influencing factors during the user test process. 95% of participants expressed that they were certainly affected by the changes of food print objects. Just like different nutritional intakes lead to different expressions being produced, their moods also changed when they saw different printouts' expressions. Participants with high nutritional intake replied that they felt happy from receiving pleasant expressions

because they achieved nutritional balance. On the other hand, participants with low nutritional intake felt annoyed and regretful by seeing negative emotions of the printouts. Some of them also indicated that the regular printing sounds they heard during the food printing process captured their attention. In addition, the printing atmosphere and the tactile sensation of the printouts also affected their emotions as well.

Moreover, the same percentage of participants prefer to change their daily dietary in order to see the changed food print and finally earned a perfect food print. Overall, 85% of participants claimed they were willing to sustaining ability to changeable model than to be recommended the selection of a printable model from the app that would not lead to any change. As a conclusion, we are pleased that our customized service received a final user rating of 8.5 (out of 10 from 20 participants).

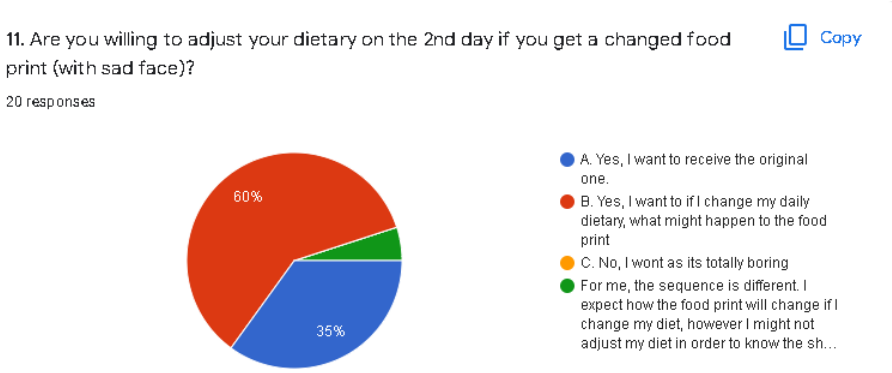


Figure 6.10 Willingness Result

1 https://docs.google.com/forms/d/e/1FAIpQLSeb2lknIO1ItHdeYzGP62J6-Lb2dSrLZbICaKnLXUZ1wTVB4A/viewform?usp=sf_link

2 https://docs.google.com/forms/d/e/1FAIpQLSf2Wq7SxIfxW84pv0hoCCnpHjcJYVrs_NsbzuxcJptTpgq8kw/viewform?usp=sf_link

Chapter 7
Discussion

7.1. Insights

This paper depicts multi-design elements that are necessary to achieve effective and enjoyable daily nutrition intake which are customization, visible nutrition intake data, dining experience, geometric variables, and adaptation of the daily dietary. In the future, these elements will be integrated and users will further use the application to learn daily dietary management and print more forms of food print.

We also intend to make further research and develop food printing technology, such as exploring the possibility of developing a portable food printer just as same as the size of an intax, as well as multi-material, color food printing. We would also like to improve the interaction between the food printing service and our users. For example, the application will remind our users of their daily nutritional intake in an entertaining way, and also provide random numbers or shapes produced entirely by the system from the print template to achieve a intense feeling of the surprise. We hope that all of our users are able to be more proactive in their daily lives to take customized nutrition intake, rather than treating it as a schedule that has to be carried out. So that, they will pay more attention on their individual daily diet management through using this service, and eventually become a sort of long-term health habits to achieve a balanced nutrition in their everyday lives.

7.2. Stimulation of Human Five Senses On User Dining Experience

In order to achieve the feasibility of widely usage of food printing in human's daily life, increasing the user experience of food printing and make new forms of stimuli becomes extremely critical. Although we proposed some design services to enhance the user experience in this paper, there is still some space for improvement such as influencing factors of food printing process and via customization features that based on feedback from participants.Some participants mentioned they enjoyed watching the food printing process and felt relaxed while the printer did the repetitive actions and produced a sort of mechanized sound. Aiming to use this technique to achieve well nutrition balance, the forms of using food printing also adds a technological element as well as the playfulness that make the daily dining experience more interesting and enjoyable for future users.

Figure 7.1 Five Senses and Dining Experience

According to results from implementation and experimentation, we summarized further possibilities to delight users while using this customized service. For example, increase some stimulation on human five sense is one of the methods to delight users. One of the exploratory hybird studies made several prototypes on multi-sensory dining experience stimuli from the academic literature, namely

1 https://blog.tabsquare.ai/the-importance-of-visuals-in-the-fnb-industry

visual (sight), tactile (touch), gustatory (taste), olfactory (smell), auditory (hearing), and design and layout, that influence guests' choice in restaurants. [25] The main purpose of their study was to investigate the multi-sensory stimuli significant to the dining experience of Middle of the Pyramid (MOP) consumers. Totally they collected 363 respondings through MOP consumers by completing a questionnaire either in online and offline. The results show that multi-sensory stimulation had been evaluated as a helpful tool to create a well-rounded dining experience. With more and more people pay a higher attention on the methodologies of providing pleasant dining experience, dining areas, pleasant food smells and surrounded music are all used as a particular weapon to atrract greater customers.

Moreover, it is undoubtedly that the phenomenon of synaesthesia has certainly inspired many artists, designers and marketers for a century ago. Chefs, in contrast, are increasingly represented as artists with their own unique style. They rarely seem to combine this elements in their culinary creations. However, this is slowly beginning to change, as a tiny but increasing number of innovative chefs are turning to surprising their guests cross-sensory connections and the related phenomenon of crossmodal correspondences, as a source of culinary inspiration as well as the innovation to their individual menu design. [26]

In a recent review of one of the famous conceptual design restaurant, critic Bill Addison calls Alinea, they concluded their concept roughly as "Unexpectedly sensual and surprising. [2]. According to their understanding of the dining experience, not only in sight and taste, hearing and smell are able to evoke guests' positive emotion as well.

7.2.1 Taste and smell

Taste is the sense that is extremely related to smell because we will smell the food when we chew it. The texture of the food can change the taste of the food. Soft textures are able to create a sort of sweet and creamy flavors, while rough textures can make a dish saltier, crunchier, or even more bitter. A real-world example. Nestle found that people responded more positively to round chocolates than square chocolates because they fit the shape of people's tongues, creating the

2 https://spoonuniversity.com/how-to/how-senses-impact-your-dining-experience

creamy, melting chocolate sensation in the mouth that most people are enjoyed with.However, the experience of taste is not able be defined by neurochemistry and physiology alone.

The philosopher Carolyn Korsmeyer mentions that taste is a sort of intimate sense that is strong and sensitive. Our olfactory system routinely manipulates complex mixtures from multiple odorants, then released from a substance that is forced into the nasal cavity while in chewing and swallowing processes. [3]These reactions enhance the palate with subtleties and also nuances. Therefore, the flexibility to manipulate these nuances will lead to greater surprise and pleasure for people's dining experience.

7.2.2 Hearing

Likewise, customers ate not only with their tongues, but also with their ears. He noted that while people are listening to Italian music while eating Italian food, they may think the food tastes more authentic. At one of the evidences, Haagen-Dazs used this finding to create a new application which allows people listening to some classical music to make their ice cream softens, thus creating a more emotional experience of eating ice cream.

7.3. Limitation

7.3.1 Customization Possibilities

This research underwent a major change in the early stages of food customization. The initial idea was to appeal to the user's daily nutritional intake in the form of various printed models. However, since the ui and ux design process, we analyzed users through different characteristics and then realized the significance of users' individual preferences for food customization as well as dining experience. In the UX design session, we successfully achieved to alter the print templates chosen by users based on their different nutrition intake parameters, thus periodically en-

3 https://www.latimes.com/health/la-xpm-2012-sep-06-la-he-food-morals-20120818-story.html

couraging them to actively adjust their daily dietary. However, in other variables, not only the facial expressions, the height, stature, weight, and even the coloring on the different parts of the print model will definitely brings more playfulness and joyfulness to the dining experience.

In addition, according to the several respondings from our user test participants, further work across customization functions are able to have the potential to be developed as well, such as nutritional diaries, reward or punishment games for nutrition balance task, and the addition of customized versions for different user demands. (simplified, regular, professional and so on)

7.3.2 Technique Possibilities

In this project, we have used roughly five different materials for food customization, which are mainly composed of various flavors of creme, flour, and surimi powder. Therefore, the obtained data points yielded computational models that can only be used for food structures with the same characteristics.Further work on other components and food hardness is also required to be generalized before the results are able to utilized into greater food categories. In addition, in terms of food printer setup parameters, our work only examined the impact of a limited number of printing parameters on the accuracy of food printing, which are extrusion multiplier, fill density, number of layers, and print level height. In other words, other parameters such as heating temperature, extruders numbers, and shell thickness may also affect the speed, accuracy, and printing time of the extruders' movement.

Furthermore, although we hope that our customized service may help users to proactively adjust their daily dietary, the current using form as an after-dinner dessert still has some sort of limitations. By considering the loss of nutrients due to heating, in the future, we expect more food types to be developed, and even they also allow to be combined with some regular dishes to eat and bring better effects.

Chapter 8
Conclusion and Future Works

8.1. Conclusion

As Contributions, this studies have demonstrated how nutritional supplementation can be achieved through customized food printing technology and a enjoyable dining experience. Rather than changing the shape of food in the usual digital method, we have also designed a series of food printing assistance apps to customize the nutritional content of food and make trans-formative food printing in a few very simple steps. We used a well organized questionnaire to detect the physical health condition of the each user, so as to obtain the missing nutrients information and indirectly help them set their future nutritional goals. We investigated how the app's database could intelligently calculate the specific nutritional content that the users are ought to achieve that day by scanning their daily dietary and determine the specific nutrients value. In addition, we determined how to enhance the user's dining experience to periodically awaken their subjective attitude towards daily dietary management and then actively engage in customized food printing. Currently, we are able to change the facial expressions of the printed models selected by the users based on their different daily nutritional intake criteria as well as show them some corresponding emotions. And according to participants' responding, they replied they were looking forward to figuring out various changes of print models in the future. [1].

1 https://docs.google.com/forms/d/e/1FAIpQLSf2Wq7SxIfxW84pv0hoCCnpHjcJYVrs_NsbzuxcJptTpgq8kw/viewform?usp=sf_link

8.2. Future Works

Future research can be inspired by the limitations already mentioned above, such as the portable size of food printers, and the efficiency of printing. Currently, food printing technology is limited by the large size of most food printers and the complexity of the associated software, and often be utilized in some experimental usage. In the future, we intend to further research and develop food printing technology, such as developing a portable food printer with the same size as the intax. In combination with the food printing assistance application developed in this study, we believe that it can be better used in people's daily life. On the other hand, based on the feedback from the user testing sessions, most of the participants claimed that they prefer to see the food printing process is able to be controlled within 10 minutes. Considering the possibility of multiple colors and materials printing in the future, we will continue to research and develop the conceptual design proposed in section 3.5.2 of this paper - food printing with multiple extruders.

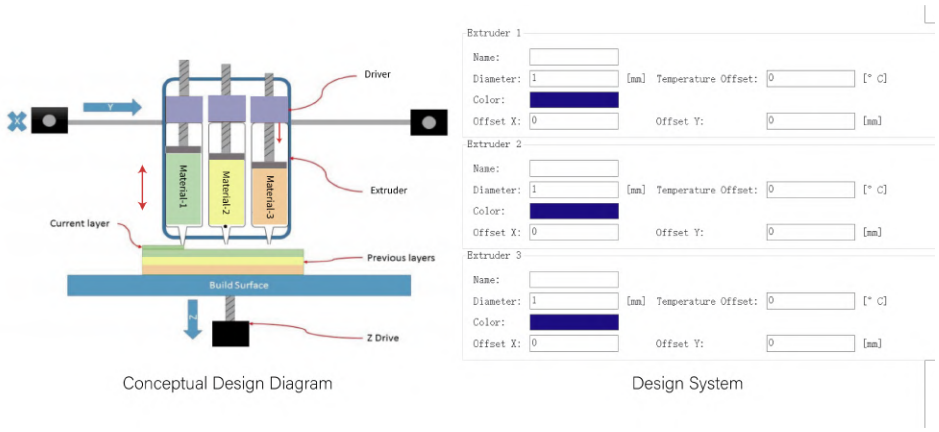


Figure 8.1 Conceptual Designs

In addition, in order to achieve a more enjoyable dining experience, we have proposed in chapter 7.2 to enhance the user dining experience by producing some stimuli from the five human senses. In the future, we will further explore the texture, smell, and surrounding environment of the raw material to be printed among the criteria that affect the user's emotion, although these possibilities for customization may lead to a convergence of greater influencing factors to be considered. Currently food printing technology is widely used in the restaurant, medical, and service industries, and we expect that in the future, this technology can expand its diversity, and be further used in more industries (education, art, social support, etc.) by customizing food printing in multiple dimensions (geometry, internal structure, materials, patterns, etc.).

Chapter 9
Appendix

9.1. Questionnaire Templates

9.1.1 Health Management

- 1.Could me tell me your age? (if you don't want to answer this question please keep it blank)
- 1.1 Please select your gender.
- 2. Have you taken the supplement products?
- 3. How long you keep using it?
- 4.Have you feel stressed or tired because of the work/ study?
- 5. How do you feel about your current health level?
- 6. Have you ever used App for health management?
- 7. How do you feel using App to manage your health?
- 8. What kinds of the service or the functions you want if there is a customized nutrition app exist? (aim to improve health issues)
- 9. How long you spend in filling health questionnaire for customizing nutrition?
- 10. Do you think its worth or not?
- 11.Do you have any other suggestions for the health questionnaire you have taken before?

9.1.2 User Experience

- 1.Have you known 3d food print before?
- 2.How do you feel using 3d food print to replace the nutrition supplement?
- 3.How do you feel the customization parts?
- 4.How do you feel about the changeable print model?
- 5.If you don't like this function, please explain your reasons.
- 6.What are you doing during the printing process?
- 7.Whats the maximum time you can accept with the food print?
- 8.How do you feel about food print models?
- 9.How do you feel about the simplicity of the whole process?
- 9.1 If you have any suggestions for the simplicity of food print, please feel free to write it here.
- 10.When the printed food has been changed from today's nutrition intake data, how do you feel about it?
- 11. Are you willing to adjust your dietary on the second day if you get a changed food print ?
- 12. Are you willing to keeping to use this service to manage your health?
- 13. How do you feel the tastes by adding to nutrition pack to the food print
- 14. If you gonna to mark this service due to the dining experience, what score you might give to it?(from 1 to 10)
- 15. Do you have any other suggestions for improvement of this project?

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