

# SHAPE-CHANGING FOOD

## RESTAURANT EXPERIENCE



# SHAPE-CHANGING FOOD RESTAURANT EXPERIENCE

## M2.2 Final Master Project

**STUDENT** Elzelinde van Doleweerd

**ASSESSORS** Miguel Bruns, Rong-Hao Liang, Aarnout Brombacher

**STAKEHOLDERS** Alchemist, Upprinting Food

### PROLOGUE

During my master I continued with my final bachelor project 'Upprinting Food' as a start-up. Upprinting Food is focused on 3D printing beautiful, tasty shapes from old bread and ugly or overripe fruit and vegetables. I have set-up a team with enthusiastic students, followed entrepreneurial programs to understand the skills and mindset of being an entrepreneur and started working on food printing with restaurants, to collaborate on the development of recipes from the products they normally throw away. While doing so, I fell in love with these collaborations and the industry and realized that I was able to contribute to developments in this industry with my knowledge on food and design. Talking with my coach, Miguel Bruns, we discussed the ultimate dream experience of my master, which resulted in an overview of the world's best restaurants to collaborate with during my Final Master Project.

With the new project on transformative food, I gained attention from new chefs, extended my network and reached a new target group of world class restaurants. Working within Alchemist has been like a dream, one of world's best restaurants, open to innovation and with room for art and design. In the beginning, I did not know how to frame myself to enter a restaurant like Alchemist, and I still constantly learn how to frame myself as a designer working in the kitchen of this Michelin-starred venue. I am constantly learning how I can make a contribution with my skills and knowledge, how I want to further develop myself and even how I believe restaurants can further develop in collaboration with designers. Both my work and journey are a research-through-design process with many restaurants on my dream list to collaborate with in the future.



## INTRODUCTION

In Human-Computer Interaction (HCI), there is a growing body of work that targets the intersection of food, technology, and human interaction [3]. The so-called space of Human-Food Interaction (HFI) is an umbrella for research that explores ways in which technology could ease, augment, make more accessible, or enrich our interactions with, through, and around food [3]. Within HFI, there are efforts to support increasingly interesting gastronomic futures. This design project is focused on a subset of that body of research: works that look at the potential of augmenting foods with shape-changing properties. Inspired by previous efforts in shape-changing materials for interaction design (e.g. [31, 33, 40]), HFI researchers are exploring how to craft shape-changing food (SCF) materials that provide chefs with new ways of surprising diners. For example, Wang et al.'s Transformative Appetite is a technique for producing pasta-like foods that change shape when cooked in water [37].

Importantly, most of the research done in the space of SCF materials has so far been technically focused; little efforts have been made into exploring how it might function in real gastronomy scenarios outside of the lab. Generally, research outcomes in this space are future-oriented speculations that are envisioned to be used in futuristic dining experiences; in the few cases where the produced shape-changing materials are ready to be eaten today, little effort has been devoted to ensure that those materials respond to the needs of diners or to support chefs to integrate them in their own creative processes.

This Final Master Project (FMP) on SCF is a continuation of the M1.2 design-research project 'Shape-changing Origami Structures' and the M2.1 design project 'Shape-changing Food: Chef's Experience'. Starting the project, the goal was to fill this gap and support chefs to integrate the food in their own creative processes. The idea of edible paper sheets was created as a form-giving tool

to develop beautiful (origami) shapes. Fruit- and vegetables were used as base materials for the edible paper sheets and chitosan was printed on top, a hydrogel which is pH-reactive, creating the shape-transformations with the material in reaction to liquids with low-pH (e.g. lemon juice). A toolkit with the material was developed and evaluated with five chefs of three different restaurants, resulting in the follow-up development steps for the M2.1 project.

In collaboration with Miguel Bruns and Ferran Altarriba (PhD candidate University of Santa Cruz), the research paper was rewritten and submitted for CHI2021 and afterwards for DIS2021. The research was not accepted by both these venues, but since we are still convinced that the research is interesting enough to put more effort in, we will resubmit it for TEI2022. Part of our writing work is used for the introduction and the related work section of this report (and the M2.1 report), updated with the last innovations in this field.

During the M2.1 project the process and material were further developed. Methods were researched to speed up the process. Stencils were developed, which made it easier to create sheets with a consistent thickness and size. To improve the foldability of the sheets, a laser cutter was used to engrave the folding patterns. Furthermore, alternatives for printing the chitosan were explored, but most of them lacked the required precision or were not reactive (yet). Next to that, new flavors were tested and research was done on the influences of fermentation and enzymatic processes on the mouthfeel and reactivity of the sheets. Together with food consultant and scientist Dr. Johnny Drain a research week was set-up at the Alchemist restaurant in Copenhagen. A PLEX workshop was organized with the chefs to develop the first directions of a dining experience while implementing the material. However, when developing the same material within the restaurant, almost no shape-transformation was shown. This was the starting point of the FMP project, creating a more consistent material.

The goals set for the FMP can be found in the FMP proposal (Appendix A). Most important was to research the factors influencing the consistency of the transformation which is a crucial factor to reach the ultimate goal of enabling chefs to develop a dish for a Michelin starred restaurant like Alchemist. The project started with the development of the consistent shape-changing material in Eindhoven, continued at the Alchemist restaurant, to research new flavors, ingredients and shapes that fits the restaurant's vision. The project is finalized with the development of two potential dishes.

---

## PICTURES

Top: Edible origami structures, M1.2 project.  
Bottom: PLEX workshop, M2.1 project.



## RELATED WORK

Various projects have explored how novel technologies can contribute to innovations in the domain of HFI. In particular, using digital manufacturing from material science to create edible shape-changing materials has gained popularity. In this section an overview provided on the research related to SCF. Furthermore research around holistic dining experiences is pointed out, as a series of concepts that are inspiring for the implementation of the SCF.

### SHAPE-CHANGING FOOD

Within food-production oriented HFI, there is a body of work that explores the potential of SCF to support chefs in creating novel dining experiences. Research is focused on different approaches, materials and target groups within this space. In 'Morphlour' grooved patterns in flour-based pasta result in a transformation mechanism that triggers the shape change by dehydration through baking and hydration through cooking [34]. In 'Transformative Appetite', pasta-like gelatin-cellulose based films are created and transformed by hydration through cooking. To show the possible implementation of the interactive food, dishes with this material were co-developed with one chef [37]. In both 'Morphlour' [34] and 'Transformative Appetite' [37], the advantage of flat-packaged food is emphasized, which also shows the intention of applying it as a finished product.

In recent research, 3D food printing of a pumpkin based puree is used to realize 4D printing of food materials, this transformation is achieved by controlling the drying time, printing path and layer thickness [5]. Similarly, starch based purees from purple sweet potato are 3D printed and transformed to 4D structures by dehydration in a microwave [8]. Both 3D to 4D transformations take more than one hour which makes this transformation unsuitable as a surprising effect for a dining experience. Other research is done with 3D printed starch-based

structures (on plastic films), in which the relationship between the material's properties, the heating mechanism and resulting shape-transformation are investigated [16]. New opportunities for directly printing food in 4D (instead of transforming 3D prints to 4D) are shown in the research 'Freeform Fabrication of Fluidic Edible Materials' [39].

Looking into the biomedical field, printing of transformative materials shows advantages for tissue engineering and drug delivery [6]. Taking a more material-centered approach, 'Organic primitives' explore pH-reactive materials in a variety of contexts, one of them being 'edible'. With the use of chitosan, pasta was created where shape transformations were defined by patterning specific areas, providing possibilities for chefs to alter the shape of the pasta to enable different levels of flavor retention or sensory augmentation [14]. In 'Natto Cells' a bio-film is created for shape-changing interfaces. This material is a living, food-safe organism and can potentially be used in actuated food [40]. Beyond sometimes the involvement of a single user, the projects described above did not explore how their technology could be extended to and appropriated by a wider audience.

Recently, new applications are shown in the field of gastronomy: 3D printing of a chocolate shape which transforms into a flower when hot chocolate sauce is poured on top, with even another flower inside is presented as collaboration between the Mona Lisa studio and well known pastry-chef Jordi Roca [22]; Rene Redzepi, head-chef of Restaurant Noma, presenting fruit leathers on his Instagram that show a certain movement (although unknown if it is reactive or the unfolding or a folded material) [11]. Developing this SCF project, it is important that chefs are not only testing the material, but can expand their scope by thinking about the shape, flavor and production methods within their restaurant, to create a surprising experience for their guests. This is the focus of this continuous development of the shape-changing material at the Alchemist restaurant.

## HOLISTIC DINING EXPERIENCE

When going out for dinner in a restaurant, not only the taste, but also the aesthetics of the food, the ambient sound [32], the shape and texture of cutlery [36], the color of a plate [27], the way we put food in our mouth, the smell [19] or even the social interactions that take place throughout the dinner have an impact on both our taste perception and on our holistic experience of the meal [30]. Consequently, to craft food experiences that are compelling, chefs use all sorts of strategies and techniques, e.g. molecular gastronomy techniques (inspired by elBulli, arguably the most influential avantgarde cuisine restaurant in the last decades [25]) to create a surprising mouthfeel to their food.

Within HFI, a body of work explores how multi-sensory stimuli can have an impact on our food experiences—both on the experience as a whole and on taste perception in particular. In this space, often referred to as Multi-sensory HFI [3] or Gastrophysics [30], researchers use cross-modal psychology techniques to investigate how the different components of a meal can be leveraged purposefully in order to enrich a dining experience.

The Alchemist restaurant is focused on this holistic dining experience, the restaurant set-up is developed in order to implement a holistic dining experience in the restaurant. Rasmus Munk, chef and co-owner Alchemist: *"Holistic dining is per definition multi-layered. It draws upon elements from the world of gastronomy, theatre and art, as well as science, technology and design, in order to create an all-encompassing and dramaturgically driven sensory experience."* [23]. The follow-up section 'Alchemist' describes how the restaurant creates these experiences.

## 1: ALCHEMIST

In this chapter, the restaurant's dining experience will be explained, the restaurant's organization and the development of new dishes within the restaurant.

### THE HOLISTIC DINING EXPERIENCE

Alchemist is a well-known restaurant worldwide and awarded as the best restaurant in Denmark [38]. The restaurant has two Michelin stars and serves a unique concept; when diners go out at Alchemist for dinner, they will go through a holistic dining journey with 50 impressions within the restaurant.

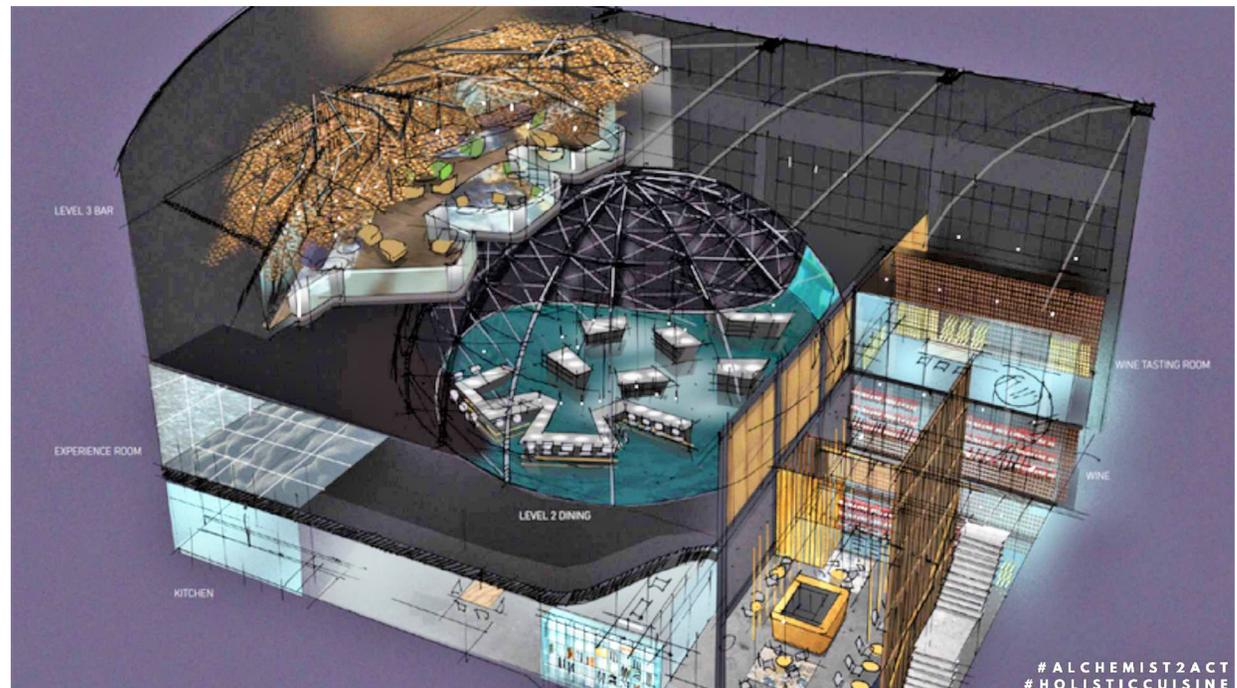
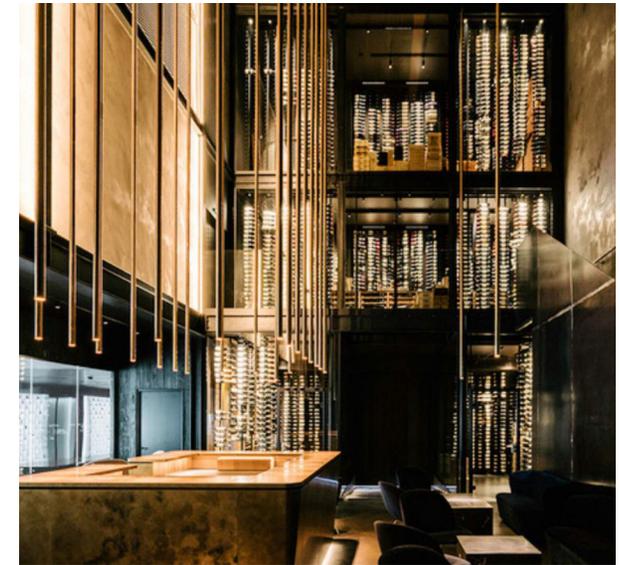
The impressions take place in the following areas of the restaurant: 1. Entrance; 2. Dark room; 3. Launch; 4. Dome; 5. Pink Room; 6. Kitchen; 7. Balcony; 8. Butterfly room. For all areas, the design of the furniture, light and use of colors, music and art is taken into account in order to create the ambiance Alchemist wants the guests to experience. Just like the dishes, the rooms (pink room, butterfly room and dark room) will be changed during the year into new settings, creating new impressions. Currently there are actors in the pink room, they amuse the guests with a performance, or even motivate guests to join in and start dancing. In the dark room, a violist gives a performance as a first impression. The dome is a dining area with a video screen in the shape of a dome. On the screen, projections are shown which are connected to the dishes served to the guests. Often there is a connection related to the ethics, the processing, sustainability issues or other topics related to the food served. The goal is to make a statement, making people think about the food they consume. On the next page three dishes are described that exemplify this.

### PICTURES

Top left: Dome, photo by Søren Gammelmark.

Top right: Launch, photo by Claes Bech Poulsen.

Bottom: Map of the Alchemist building.



#ALCHEMIST2ACT  
#HOLISTICCUISINE



**NUMBERS**  
 ALCHEMIST  
 2.200 m2  
 4 Floors  
 2 Art installations  
 50 Impressions  
 48 Seats  
 4 Kitchens  
 37 Chefs  
 22 FOH  
 1 Dramaturg  
 2 Actors

**STUDIO**  
 4 3D Designers  
 1 Graphic Designer  
 1 Sound engineer  
 1 Plastic designer

**EXPLORE**  
 1 Food Scientist  
 3 Research assistants  
 5 Chefs  
 7 Academic collaborations  
 2 Scientific articles



1. *Plastic Fantastic*  
 A comment on the fact that up to one third of all cod caught in Northern Europe contains plastic. Even in the Mariana Trench at 11 kms depth microplastics were found in the tiny shellfish that live there. This dish is served in the dome, in the dome animations are shown of the ocean, with sea animals and pieces of plastic. Even some of the animals are caught in plastic or related to the Covid-19, mouth masks.

Dish details: Grilled cod jaw brushed with smoked bone marrow and grilled. It is topped with a cream of Comté cheese. The "fantastic plastic" that tops the dish is made from a dehydrated cod skin bouillon.

2. *Burnout Chicken*  
 The chicken leg is served in a cage with the same diameter as the floor space a conventionally farmed chicken has to its disposal. To eat it, you must first set the chicken free of its cage. In the dome the small cages with chickens are piling-up until the full dome is covered.

Dish details: A deboned chicken wing (from Hopballe Mølle in Vejle [9]) stuffed with a soufflé of chicken, glazed with teriyaki sauce infused with lobster and topped with burnt hay.

3. *Food for Thought*  
 A tribute to foie gras producer Eduardo Sousa who figured out a way to produce natural foie gras from wild geese that land in Spain once a year to feast on acorns and olives before migrating further south (instead of force feeding the birds). The dish comes inside a faux human head, you have to remove the top of the cranium to reveal the content.

Dish details: Sautéed foie gras in a Madeira casing topped with yuzu gel and aerated foie gras.

Next to the holistic cuisine, Alchemist has some side organizations to grow their community and impact. One example is Junk Food, an organization started within Alchemist, cooking food for homeless people

[13]. Also, they collaborate with a hospital, for which they contribute in the development of a new menu. Furthermore, they develop a YouTube channel for children, in which they share stories and recipes for magic food experiences. Alchemist Explore (the research and development section of the restaurant) will become a separate company in the near future, publishing academic research, and researching new ingredients and materials for the menu.

**RESTAURANT ORGANIZATION**

To develop this unique set-up, the restaurant can be divided in Alchemist (the daily restaurant), Studio (graphic, 3D and music designers) and Explore (R&D). These sections are closely related, but have their own meetings and responsibilities.

The development of this project is part of Explore. Explore can be divided in a Research, Development and Beverage program, the structure of Explore can be found on the next page. The material research and research output of the SCF is part of the Research section of Explore, the development of the dish is part of the Development section of Explore.

**DISH DEVELOPMENT**

The goal of the collaboration in this project at Alchemist is to enable the chefs to start working with the material themselves, and possibly implement it in their menu when a dish is developed. Therefore, it is important to understand the process of developing new dishes in the restaurant. The steps of this process are described below. Step 1 to 6 can separately take one or multiple months, steps 7 to 11 can take place in one week.

1. Brainstorming and ideas selection:  
 In monthly meetings, Rasmus Munk (head chef and owner of the restaurant), Theis Brydegaard (head of development) and Diego Prado (head of R&D) have a brainstorm session and select ideas for development, both for research and development in the kitchen.

## PICTURES AND FIGURES

Previous page

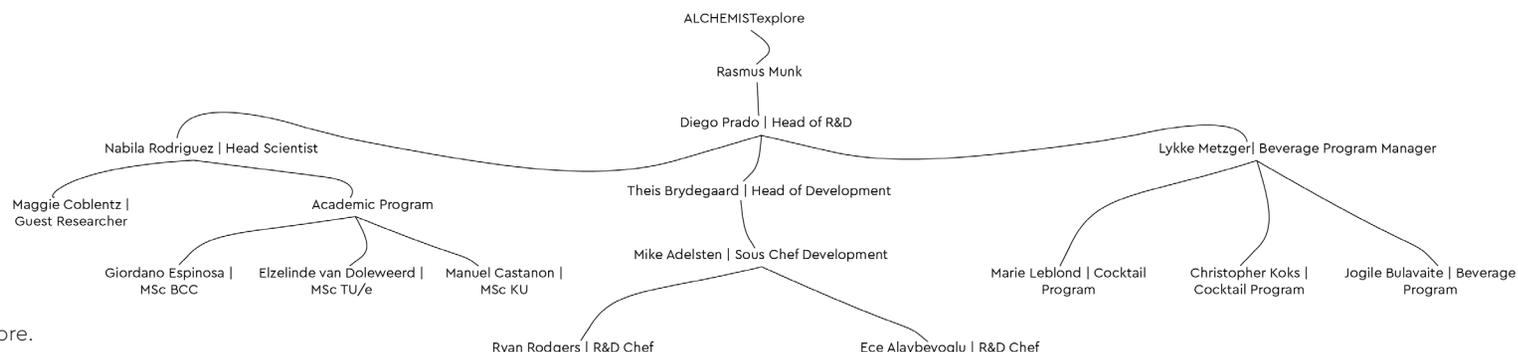
Top: Plastic Fantastic\*.

Center: Burnout Chicken.  
Photo by Thomas Lekfeldt.

Bottom right: Food For Thought\*.  
\*Photos by Claes Bech Poulsen.

Bottom left: Alchemist numbers.

Current page: structure Alchemist Explore.



In general, everyone can come up with a new idea, Rasmus is the person who needs to greenlight it. Sometimes Rasmus has an idea and can ask for something to be developed without directing how it should be developed. The development team can focus on expanding on this idea and Rasmus will give feedback as soon as they have something to show or taste.

Some of the ideas are larger projects, e.g. collaborations with external researchers, universities or external companies. The outcomes of these collaborations can either lead to new ingredients or processes, or they are solely focused on growing the community or promoting the restaurant (e.g. the YouTube channel, the hospital collaboration and the Junk Food project [13]).

2. Development: For dishes, one of the development chefs continuously works on an idea. It can be a ready-to-implement ingredient, it can be the preparation of (a) new food ingredient(s) that needs to be researched or it can be a broader concept.

3. Weekly tasting and design developments: Every Friday, a meeting is planned with Rasmus Munk, Theis Brydegaard, Mike Adelsten (development sous-chef) and eventually Diego Prado. The work on the development of the dishes will be presented by the development chefs and evaluated afterwards. With the feedback of the evaluation, the chefs can continue with the development or they have to

stop the process if they do not expect any positive outcome. It can take one or even multiple months before Rasmus and the other chefs are satisfied to implement the dish in the restaurant.

3b. Tableware selection: During the first month of the dish development, the idea will grow and the development chefs and Rasmus will start thinking about how the dish can be served. External parties will be contacted for the design of a new plate, bowl or specific cutlery. Some ideas will be visualized with 3D-printed prototypes or simple drawings, in order to communicate with those parties about the shape and sized of the plates. Multiple prototypes will be developed by the external parties and evaluated at the restaurant. The size of the final dish plays an important role, just like the colors and the story behind the dish.

3c. Meeting with studio: Next to the development of the tableware, a meeting with the Studio (3D designers, graphic designers, music designers) will be planned every month in order to discuss what is needed for the new dish. This can be e.g. prototypes of new tableware, content for the dome, music in a specific area of the restaurant where the dish is served or graphics for the menu.

4. Dish approval: When the dish is approved by Rasmus, the dish will be presented to the beverage program. The sommeliers will choose one or two wines to pair with the dish. A non-alcoholic drink will be developed as well.

5. Rehearsal: The dishes will be presented to Rasmus, the two head-chefs of the kitchen, the beverage program manager, the head-sommelier and sous-sommelier.

6. Premiere: A final tasting with the two head-chefs of the kitchen, two sous-chefs, the head-sommelier and sous-sommelier, the PR-manager, the beverage program manager, and the head of non-alcoholic beverages.

7. Orders: It needs to be checked with the head-chefs of the kitchen if the ingredients are available to produce the dish for enough people in the follow-up week.

8. Mise en Place (MEP, Monday-Wednesday): Theis and sous-chefs will work in the kitchen on the MEP.

9. Presentation (Thursday): The dish will be presented to the Front of House (FOH) and the kitchen, a presentation will be shown to provide the chefs with the story and background information of the dish and ingredients.

10. Alchemist Tables (Thursday same day of the presentation): The dish will be served for Alchemist tables (VIP guests).

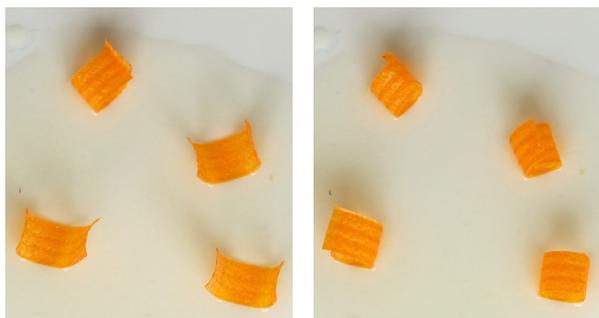
11. On the menu (Friday same week): The dish will be served to all guests.

## 2: A CONSISTENT TRANSFORMATION

During the M1.2 research project, the first recipe was developed for the transformative material. Edible paper was made from carrots and a chitosan solution was printed on top. The paper was foldable in beautiful shapes, but the transformation of the paper could take multiple minutes and was not consistent yet. Those aspects are crucial for implementing the material in a high-end restaurant. The M2.1 project was focused on speeding up this process. Stencils were developed, which made it easier to create sheets with a consistent thickness and size. This led to a great improvement in transformation speed, but when developing the paper with the same recipe at the Alchemist restaurant, it rarely showed any response.

To continue with this project in a restaurant setting, the most important step was to find out the factor which caused the difference in reactivity. Starting with the M2.2 project, measuring and analyzing every step of the process precisely was needed, including the ingredients and equipment used. Possible factors which can influence the reactivity were described in the FMP proposal. In step a to d below, the evaluated factors are described. An overview of all experiments and calculations done to validate these steps can be found in Appendix B.

For most experiments, the reactivity of edible sheets is compared. This is done by measuring the reaction



time of the rolling up reaction of the sheets. The sheets printed with chitosan are cut in pieces of 10 mm x 30 mm. For each experiment at least three of these 10 mm x 30 mm pieces are tested. The reaction time is the time measured from placing the piece of paper on the reaction liquid until the paper is rolled-up and two opposite sides are touching each other. All sheets are filmed and analyzed to measure the duration of the reaction.

### *a. The activation-time of the thickening agents in the puree.*

The puree to make the edible paper sheet consists of a base ingredient (e.g. carrots) and five additives: wheat starch (0.8%); glycerin (3%); algin (1.2%); agar (0,1%); carboxymethylcellulose (0,1%). These additives are binding-agents, adding them to the base will result in a smooth puree to form sheets with the right dryness and flexibility to print on top of and fold into an origami structure. It is observed that the carrot puree with the additives becomes a thicker substance when set in fridge overnight. Sheets were formed with a puree directly (not set overnight). Their reactivity was compared against sheets which were made with a puree which was set overnight (Appendix B: Test set 1). The hypothesis was that this thicker puree could result in smoother sheets and a faster reaction time. The sheets which were made without a delay were indeed less smooth and contained more air bubbles, however there was no clear difference in reaction time between the sheets.

### *b. The dehydration temperature and time of the paper sheets (without chitosan).*

The dehydrator which was used in Eindhoven (TurboTronic TT-FD30D) is a different brand of dehydrator compared to the dehydrator at the Alchemist restaurant (Excalibur 4926T220FB). The fan in the dehydrator at the Alchemist restaurant has more power, resulting in sheets which were 'flying' through the dehydrator, which led to them folding instead of staying flat. The power could only be

reduced by reducing the dehydration temperature. To test whether this factor influenced the reactivity of the sheets, sheets were dehydrated at temperatures between 40 (lowest setting at the dehydrators at Alchemist) and 80 degrees Celsius (highest setting of dehydration used in the Netherlands). Next, their reaction time was analyzed (Appendix B: Test set 1). For the first test set, three different dehydration temperatures were chosen: 45 degrees, 65 degrees and 75 degrees Celsius.

The resulting reaction times were as follows:

- 75 degrees Celsius: between 15 and 45 seconds.
- 65 degrees Celsius: between 20 and 40 seconds.
- 45 degrees Celsius: between 8 and 35 seconds.

While comparing the influence of the dehydration temperature on the reaction time of multiple sheets and recipes, the results were similar. A temperature 45 degrees Celsius resulted in slightly faster reaction times, but because of the multiple variables tested (Appendix B: Test set 1) and the minimal difference, it cannot be stated that a dehydration temperature of 45 degrees Celsius will always result in a faster reaction of the sheets. However, dehydrating at 45 degrees Celsius offers the benefit of being able to dehydrate with a lower fan power at the Alchemist restaurant. Follow-up experiments were done with dehydration temperatures of 45 and 40 degrees Celsius (Appendix B: Test set 2) which did not provide a clear difference in reactivity of the sheets. This is why the dehydration temperature of the process is changed from 80 degrees to 40 degrees Celsius.

Since there is a clear difference in fan power of the dehydrators, no standard dehydration time can be provided in the final recipe. However, it became clear that it is best to print the chitosan on the sheets while the sheets are still connected to the silicone (see step c). Therefore, the (unprinted) sheets should be taken out of the dehydrator as soon as they are dry to the touch, otherwise they will detach from the silicone. In the final recipe, chefs will be advised to

regularly check (every 15 minutes) after the sheets have been in the dehydrator for 45 minutes.

*c. Dehydrating the carrot-chitosan sheets while stuck to the silicone sheets compared to dehydrating the sheets separately.*

The chitosan is preferably printed on top of the carrot-sheets when the sheets are still connected to the silicone, because this allows the sheets stay flat and in place. However, after the chitosan has been printed, it is possible to take the sheet off the silicone. During the M2.1 project it became clear that dehydrating a sheet which is taken of the silicone results in a different look and feel of the paper, a ribbed stiff sheet, compared to flat sheets when dehydrating it while the sheet is still connected to the silicone. Because of the ribbed pattern it was more difficult to process, e.g. to cut or to fold in origami structures afterwards. It had not been tested yet if a ribbed pattern or a flat sheet resulted in a faster reactivity of the sheets. In addition, the paper with printed chitosan solution can be dehydrated at room-temperature or in the dehydrator at low temperatures.

The sheets were tested on reactivity at two moments: the first moment within a few days of printing the sheet; the second moment after at least another week (Appendix B: Test set 1). Testing at the first moment showed only a complete rolling reaction for the sheets with the ribbed patterns. During the second test, both sheets were clearly reactive and rolling up. The flat sheets turned out to roll up straighter instead of diagonally and stayed in shape for a longer period of time, instead of quickly unrolling again.

The project Morphlour [34] clearly shows how a ribbed pattern can lead to a particular movement of the material. One possible reason for the reactivity of the sheets is therefore this ribbed pattern. Another argument of the reactivity during the first test is the dehydration time on both sides of the paper,

compared to dehydrating on only one side because of the connected silicone sheet. This is further researched and explained in step d.

Since the flat sheets are easier to process (e.g., fold or laser cut in shapes) and provide a better structure (more flexible instead of stiff), it is preferred to continue with these sheets. Comparing these sheets at two moments lead to the discovery of an important factor of the reactivity of the sheets: the dehydration time of the printed chitosan pattern. More research was needed to discover the specific



dehydration time of the printed chitosan (while connected to the silicone), which can be found in step d, below.

*d. Dehydration time of the sheets with the printed chitosan pattern.*

To test how many days the chitosan needs to dry to show the roll-up reaction, the reactivity of the carrot sheets was tested daily. After printing and dehydrated overnight, two sheets were taken off of the silicone and three small pieces of each sheet were tested (see figure current page, sheets O2 and O3). All tests are filmed and can be found in Appendix C. More details about the measurements and outcomes can be found in Appendix B: Test set 2 and test set 2b. After drying for one day, no reaction was shown, on the second day, the first movements took place, on the third day most sheets did roll up and on the fourth day all of them did show a clear reaction.

More tests were done in which the following influencing factors were compared:

- Sheets which were taken off of the silicone on the day of testing were compared to sheets which were taken off of the silicone as soon as the chitosan was dry to the touch: the sheets which were taken off of the silicone on the day of testing were not reactive and needed three more days to dry, they were tested daily after taken off the silicone (see figure current page, sheets O8 and O10).
- Dehydrating the sheets in the dehydrator or in open air: the chitosan was dry to the touch in the dehydrator after half an hour, which can speed-up the process if limited silicone sheets are available. Next to that, some visual aspects of the sheets dried in the dehydrator came to front: the chitosan pattern was shinier; the stripes were not soaked into the paper, but more laying on top; and the sheets turned out really flat. There was no clear difference in reactivity (see figure

current page, sheet PP2).

The three days of drying of the sheets with the printed chitosan pattern is a key factor in the reactivity of the sheets. To clearly sum up the final dehydration process of the printed sheets:

The sheets are printed and transferred to the dehydrator at 40 degrees Celsius. As soon as the chitosan is dry to the touch, they are detached from the silicone and put in the dehydrator at 40 degrees Celsius for at least five hours. The sheets further need to dry for another 3 days in open air and will be able to show the shape-transformation afterwards.

The insights from this process were developed in

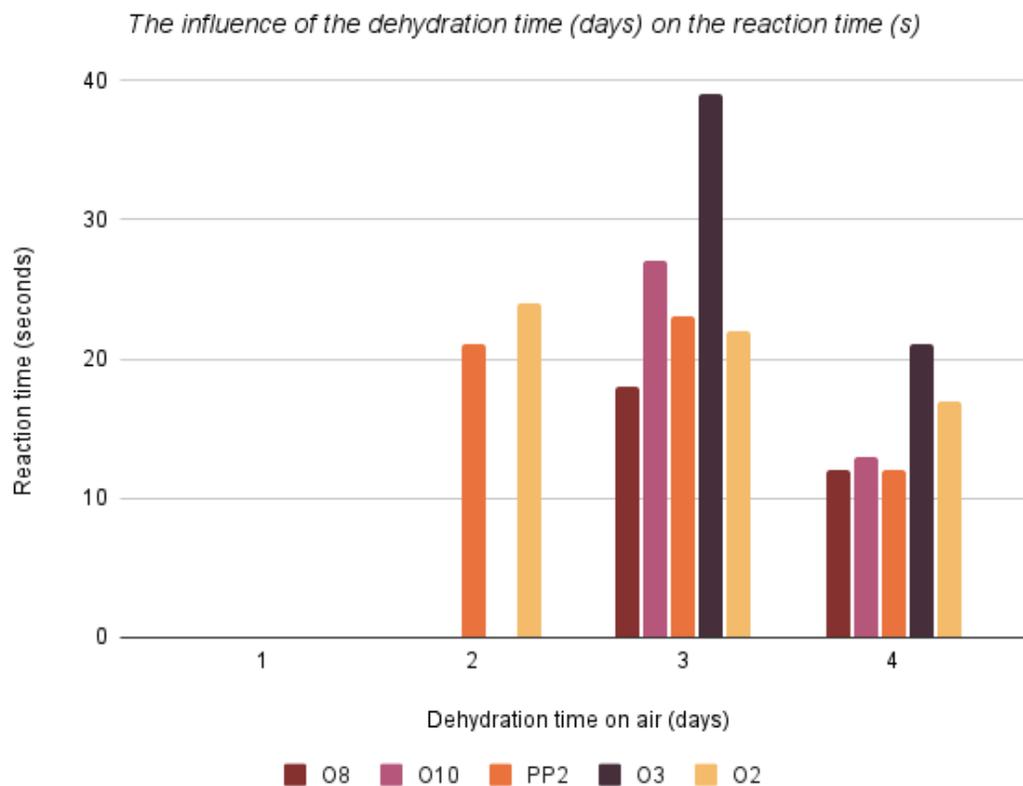
the first six weeks, before the project continued at Alchemist. In the follow-up chapters, more changes will be made to the preparation method and recipe. The final recipe and preparation method can be found in 'The final recipes'.

PICTURES AND FIGURES

Page 8: Measuring the reaction time.

Previous page: Ribbed stiff sheets and flat sheets.

Current page: The influence of the dehydration time on the reaction time, showing the average time per day of five different sheets: O2, O3, O8, O10 and PP2.



### 3: SPEEDING UP THE PREPARATION PROCESS

A fast process is important, since it should be possible to serve 50 sheets of paper in a restaurant daily. The key factor in speeding up the process is the printing of the chitosan solution on the edible paper. During the M1.2 research project it became clear that it was needed to print at least two layers of chitosan solution on top of each other (on top of the edible sheets) to create reactive sheets. The chitosan solution is quite thin, to print two layers of the pattern, the chitosan was printed, air-dried and a second layer was printed on top. While drying the first layer of chitosan in air, the sheet had to stay at exactly the same place on the printing platform, since a second layer needed to be printed at exactly the same position. This resulted in a certain waiting time in the process. With only one printer in a restaurant, this process could take half an hour for each sheet of paper, whereas the printing process itself only takes around 2 minutes.

A minimal dehydration time can speed up the production process. It was needed to test if the dehydration time of the chitosan layers influenced the reactivity of the edible paper sheets (3.1). To print two layers of chitosan directly on top of each other (instead of drying the first layer in open air before the second layer was printed), thickening ingredients e.g. algin can be added to the chitosan solution. However, these thickening agents might influence the reactivity of the chitosan, which resulted in non-reactive sheets during the first test in the M2.1 project. Tests were done with lower percentages to find out if the thickened chitosan can serve as a solution (3.2). Also, alternatives for 3D printing were evaluated, the use of a squeeze bottle (3.3) and striped silicone stencils (3.4).

*The dehydration time of the chitosan layers and thickening the solution (3.1; 3.2):*

Three new chitosan solutions were made with additional algin (added percentage relative to total

solution): 3,0%; 1,5%; 1,0% (Appendix B: Test set 2, PP4, PP6, PP10). More research was found regarding the thickening of a chitosan solution with algin [21]. The percentages used in this research differ from 1 – 10% alginate. In previous tests during the M2.1 research 6% algin was used, which was not reactive at all. The chitosan solutions with 3,0%, 1,5% and 1,0% algin were printed as two layers directly after each other. The 3,0% and 1,5% solutions were thick and hard to print (drops instead of continuous lines). After dehydration the chitosan pattern was very hard, resulting in an unpleasant mouthfeel. The paper sheet with the 3,0% and 1,5% chitosan solutions showed some intention for a reaction but did not really react in the end. The 1,0% did react very slowly. Since this percentage was already quite low, it was tested if it was possible to print two layers of chitosan solution directly after each other without any additives and without a dehydration period in between.

In Appendix B: Test set 2, sheet PP8 and PP9 show the results of printing two layers of chitosan directly on top of each other. The chitosan solution is relatively thin, which resulted in wider, but also taller lines. Both sheets turned out to react quickly. For the final recipe new chitosan printing patterns were developed which automatically extruded two layers exactly on top of each other. The development of the patterns is further described in section 4: Shaping the food. Printing two layers on top of each other directly, reduces the time and effort needed in the production process in the restaurants. The 30 minute wait time, with two times 2 minutes of printing is eliminated. This resulted in a process of 3 minutes of printing for each paper sheet.

*The use of a squeeze bottle/silicone stencils (3.3; 3.4):*

For certain shapes it can be easier to cut out the shape with a laser cutter and add the chitosan by hand instead of using a food printer. A squeeze bottle was used to test this on lasered butterflies. While testing the reactivity, the wings of the butterflies

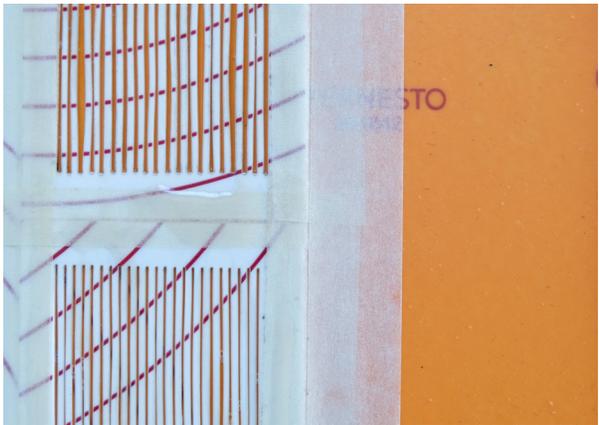
ended up moving, but not in the preferred direction. This showed that a relatively imprecise tool like a squeeze bottle will not suffice. More precision is needed for consistent transformations.

Two stencils with striped patterns (with a difference in the width of the lines) were laser-cut out of silicone (Appendix B: Test set 2, PP5). With a spoon the chitosan solution was spread out in the grooves. After a day, the stencils were removed and the chitosan was further dried for four days. The lines were not consistent in height and although the spreading into the stencil was done carefully, some lines were partially missing. When testing, the sheets were visibly reactive but not consistent. Sometimes the reaction took a relatively long time and the rolling direction was often diagonal instead of straight. More research can be done with stencils to make the material available for a larger target group (chefs without a food printer). Because of time limitations of the project and the availability of 3 food printers in the restaurant (one belonging to Upprinting Food [35], two by byFlow [4]) and their precision, it was preferred to continue with the food printers.

PICTURES:

Next page, top: Lasered butterflies, chitosan is added by hand using a squeeze bottle.

Next page, bottom: Silicone stencils with striped patterns are used to create the striped chitosan patterns on carrot paper.



#### 4: THE CHITOSAN SOLUTION

The chitosan solution was developed during the M1.2 research project. The following recipe was used:

- 50% v/v water (tap water)
- 50% v/v vinegar, (natural vinegar AH,biologic, pH 2.6, acetic acid percentage 4%) [1]
- 6% w/v chitosan, (Oxford Vitality) [26]

Since different vinegars and chitosan powders (and flakes) were available at Alchemist, research was done into the reactivity with different vinegars and powders. The vinegar can even serve as a flavor or color component (e.g. a black chitosan pattern can be developed with balsamic vinegar).

While adding the chitosan powder to water, it does not dissolve and the water will become cloudy. As soon as the vinegar is added to the mixture, the chitosan will start to dissolve, and the mixture will start to become thicker and more translucent. It is important to first add the water, if the chitosan is added to the vinegar directly, the mixture will start to clump.

##### THE CHITOSAN POWDER

Chitosan can be found in a wide range of natural sources, example sources are crustaceans, fungi, and insects [29]. The chitosan powder available at the Alchemist restaurant, was of the brand Biorigins [24]. The color of this chitosan powder is white instead of brown like the Oxford Vitality powder. Chitosan flakes were available as well, they were developed in the restaurant from crab residuals.

The different types of chitosan were all dissolved according to the recipe above. The flakes did not dissolve well. Both the white Biorigins chitosan and the Oxford Vitality chitosan dissolved using this recipe. Comparing those mixtures, clear differences were visible in the viscosity. The white chitosan resulted in a translucent solution without color and





was much thicker and elastic compared to the brown chitosan. The chitosan powders both have a high deacetylation degree of 90%, which results in a good solubility in water [17].

Shepherd et al. have researched chitosan and its functional properties [29]. Six types of chitosan were compared, the appearance of the squid pen chitosan was clearly different compared to the other types of chitosan and showed similarities with the white chitosan powder of the brand Biorigins. The squid pen chitosan was the only type resulting in a clear transparent film and the solution was more viscous with larger yield stresses. On the Biorigins chitosan packaging, chitosan is described as 'deep sea squid extract'. For this reason and the similarities of the researched squid chitosan it is assumed that the chitosan source is squid pen. The Oxford chitosan is produced from crab and shrimp shells, this information was requested from the producer.

The reactivity of both chitosan was compared, combined with different (percentages of) vinegars(s) (25%v/v, 33% v/v, 50% v/v, the 33% v/v was combined with a higher percentage of 8% w/v chitosan) (Appendix B: Chitosan Experiments). There was no clear difference in the average reaction time when the chitosan solutions were made with the 50% v/v vinegar. However, with the 33% and 25% vinegar

the Oxford chitosan showed a faster average reaction time:

- 33%: 21 seconds (Oxford) and 38 seconds (Biorigins)
- 25%: 32 seconds (Oxford) and 58 seconds (Biorigins, some of the sheets did not react at all).

Because of the thickness and elasticity of the squid pen chitosan, the solution was difficult to print. After dehydration, this also resulted in tougher lines, which were difficult to cut (the lines easily broke) and gave a more plastic-like mouthfeel. Because of these textural properties and the reactivity, the Oxford chitosan is used for the further development of the material.

#### THE PERCENTAGE OF VINEGAR IN THE CHITOSAN SOLUTION

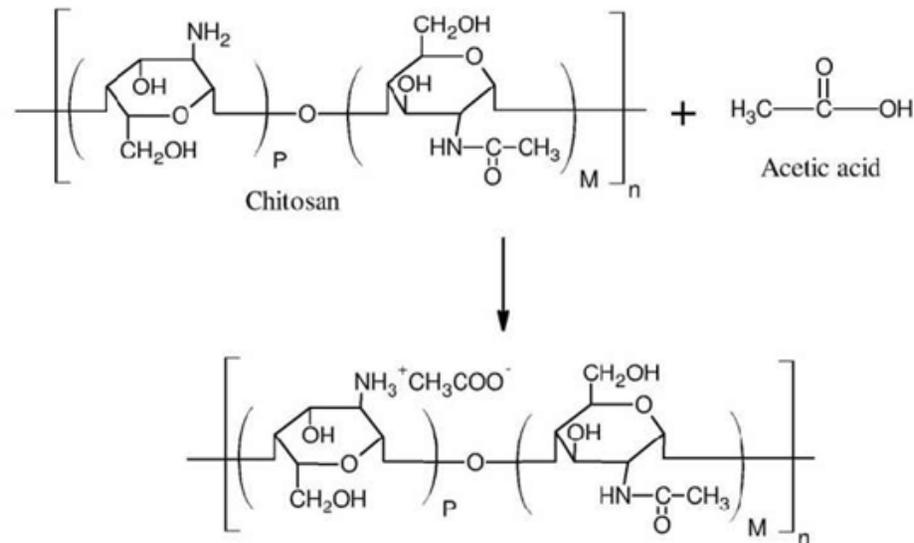
The vinegars available for the development at the Alchemist restaurant were from the brand Carlsberg, a basic vinegar was available with an acetic acid percentage of 5%, pH 2.3 and apple vinegar was

available with an acetic acid percentage of 6%, pH 3.6.

The apple vinegar and basic vinegar were compared, while using a similar process (the solutions were printed on the same day, on sheets made with the same carrot puree, using the same stencils for the thickness, printing two layers with dehydrating in between, tested on the third and fourth day after printing). For each sheet, three sample pieces of 10 mm x 30 mm were tested. The apple vinegar showed an average reaction time of 17,5 seconds, the basic vinegar showed an average reaction time of 27,3 seconds (Appendix B: Chitosan Experiments). Next to that, in the basic Carlsberg vinegar one of the ingredients is salt, which can influence the reactivity [18]. Because of the reaction time and the purity of the vinegar, it was decided to continue with the apple vinegar for the further development of the material.

Since the apple vinegar had a higher percentage of acetic acid (6%) compared to the vinegar used in

Reaction chitosan protonated in acetic acid, forming polycation chitosan [41].



the Netherlands (4%), two different solutions were tested. The recipes as developed in the Netherlands with 50% v/v vinegar, 50% v/v water and 6% w/v chitosan (1) was compared with 25% v/v vinegar, 75% v/v water and 6% w/v chitosan (2). The first solution resulted in an acetic acid percentage of 3% and a pH of 4.6, the second solution resulted in an acetic acid percentage of 1,5% and a pH of 5.4.

It was clearly visible that the chitosan solution with an acetic acid percentage of 1,5%, pH 5.4 was thicker and more elastic. Furthermore, it could be observed that some of the chitosan powder still had not fully dissolved, which can be caused by the pH which is close to pH 6.0. According to the research of Merlo, Elodie, et al. a pH below 6.0 is needed to fully dissolve the chitosan powder [20].

The acetic acid molecules are available to protonate the chitosan (see reaction chitosan + acetic acid). The protonated chitosan molecules will form a network due to the crosslinking of the chitosan. However, when more vinegar is used, the pH decreases, and acetic acid molecules are widely available. The decreasing thickness of the solution of chitosan with a lower pH can be reasoned with the amount of acetic acid molecules. The molecules will not only create the network of chitosan but will also protonate other available molecules in the vinegar or protonate separate chitosan molecules. Because of the repulsion force of these protonated molecules, there will be an increasing particle-particle distance, leading to a thinner chitosan solution [10].

A chitosan solution was also made with only apple vinegar (100% v/v and 6% w/v chitosan) to compare the thickness of this solution. This was a solution with 6% acetic acid and a pH of 3.8. The result was an even thinner solution compared to solution 1. The chitosan solution made with the vinegar in the Netherlands had a pH of 5.2 and an acetic acid percentage of 2%. This solution was slightly thicker compared to solution 1 with 3% acetic acid. It can be concluded that the percentage of acetic acid has a clear effect

on the thickness of the solution, a lower percentage of acetic acid (thus a higher pH) will result in a thicker solution. At least 2% acetic acid is recommended to fully dissolve the chitosan.

#### THE SHAPE-TRANSFORMATION OF THE CHITOSAN SHEETS

Hydrogels are cross-linked polymers with high capacity for water absorption. The hydrophilic groups (amine (NH<sub>2</sub>) and hydroxyl (-OH) are the hydrophilic groups of chitosan) enable the hydrogel to absorb water which results in the swelling of chitosan [2]. Chitosan can be seen as a smart hydrogel, a hydrogel which swells and contracts in response to external conditions [18]. The shape transformation (rolling and folding reaction) of the edible sheets with the 3D printed chitosan, is the result of this swelling process.

There are many structural factors that influence the degree of swelling of the hydrogel, and the reaction liquid can influence the swelling characteristics. For the development of this transformative material the degree of crosslinking of the network and the pH of the swelling medium were researched. Higher crosslinking of the polymer network of chitosan, results in less swelling of the chitosan in reaction to a (low pH) liquid. It is needed to have protonated (ionic) groups in the chitosan network which will result in an increase of the swelling reaction, because they are more strongly solvated compared to non-ionic groups [18]. Because of this, it can be concluded that in the 1,5% acetic acid chitosan solution (as discussed above: the percentage of vinegar in the chitosan solution) more vinegar (acetic acid) is needed to fully dissolve the chitosan and thus, create an optimal swelling reaction. Also, with higher percentages of vinegar, more chitosan will be protonated, which will contribute to this optimal swelling reaction.

The swelling of the chitosan network is dependent on the pH of the reaction liquid, where an optimum is found for pH 3 and pH 8. These optima are caused



by the high repulsion on the amino, NH<sub>3</sub><sup>+</sup> groups of the chitosan in low-pH liquids and -COO<sup>-</sup> groups in high-pH liquids. At values below or above these optima, a screening effect appears: a decrease in the interaction on the ions caused by the counter ions of the reaction liquid. This will limit the swelling. The pKa of chitosan is around 6.4, the ionization takes place above this value. At pH 4–6 most of the base and acid groups are non-ionized, which may lead to a decrease in swelling [18].

The reactivity of different chitosan solutions was tested in lemon juice (pH 2.2), apple juice (pH 3.3), coffee kefir (pH 4.4) and sparkling water (pH 6.13). The sparkling water showed the fastest average reaction time, 23,4 seconds, and the apple juice the slowest 31,2 seconds (Appendix B: Chitosan Experiments). These results showed the opposite from the expectations based on literature, however there are many other molecules that can play a role in this interaction, e.g. the salt content [18] and the sugar content [2] can influence the reactivity. The reaction with the sparkling water resulted in sheets that fell apart, which might be caused by the carbon dioxide molecules in the liquid. For the final dish development, the shape-changing paper sheets will

be tested in several solutions, if needed, the pH can be raised or lowered to a value of around 3 or 8 [18].

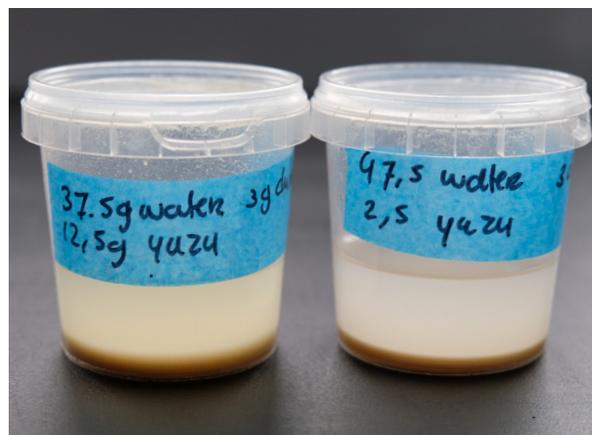
## YUZU AND KOMBUCHA

Chitosan solutions were also made with yuzu juice (pH 2.5) instead of vinegar and a sour kombucha (pH 2.9), as new flavor options and to test the dissolvability in other acids. The vinegars consist of acetic acid, yuzu can contain of a maximum of eight organic acids, with citric acid as major acid (ranging from 2.97 to 4.75%), followed by malic acid (0.21 to 1.00%) [42]. Kombucha is a made by fermenting tea with sugar with a symbiotic culture of acetic acid (producing) bacteria and yeast. Acetic acid producing bacteria make use of glucose to produce gluconic acid and ethanol to produce acetic acid. These are the two most predominant acids, the percentage of acid depends on the fermentation time, sugar concentration and liquid (tea or e.g. fruit juices). Next to these two acids, the kombucha can also contain of glucuronic, citric, L-lactic, malic, tartaric, malonic, oxalic, succinic, pyruvic and usnic acid [12].

An aged kombucha was used with a pH of 2.9. A mixture was made with 50% v/v kombucha, 50% v/v water and 6% w/v chitosan. The chitosan dissolved and the mixture started to thicken. The color was darker, because of the dark colored kombucha and in the chitosan solution the taste of the kombucha remained.

Adding the chitosan to a mixture of 50% v/v yuzu juice, 50% v/v water and 6% w/v chitosan resulted in a cloudy mixture, the chitosan did not dissolve. Tests were done with several (both higher and lower) percentages v/v yuzu juice. 100% yuzu juice resulted in a cloudy solution, which was still thin, but clearly started to gel.

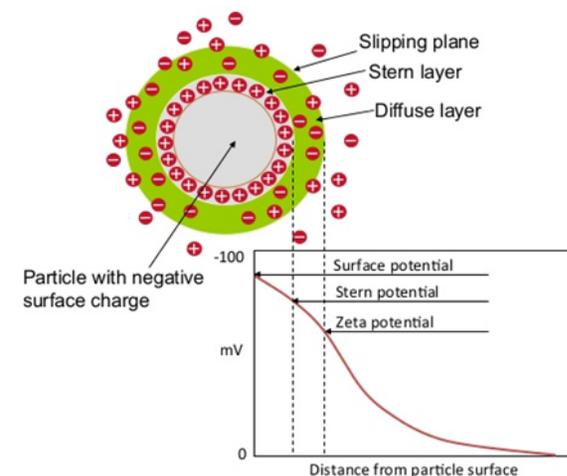
As shown in the reaction of chitosan on the previous page, chitosan is a charged molecule at low-pH values. In the research of Melro et al. [20] it is shown



that the zeta potential of the chitosan solution, the electrical charge of the electrical double layer [15], is influenced by the pH of the solution, but also by the type of acid used. Citrate (deprotonated citric acid) has a higher water-solubility compared to acetate ions. Because of this, a lower affinity for citrate is expected and better interactions are expected for the acetate ions. Negatively charged acetate ions can stabilize the electrical double layer of the chitosan, resulting in a higher zeta potential and a more stable solution. Lower expansion of the chitosan chains is expected when using citric acid, resulting in a poor stabilization of the electrical double layer, a lower zeta potential and a lower viscosity of the chitosan solution made with yuzu juice [20].

For the development of more flavorful chitosan solutions, it is important to look for liquids containing acetic acid to fully dissolve the chitosan. It is possible to dissolve the chitosan using kombucha, but the percentage of acetic acid is difficult to measure (and will even develop during the fermentation process of the kombucha). For the continuous development of the material, vinegars with known acetic acid percentages are used. The further development of the chitosan(solution) as flavor component is described in 'Flavor development'.

Electrical double layer and zeta potential [15].



Abd Karim Alias, 2013©

## PICTURES AND FIGURES

Page 13, top: Dehydrated chitosan structures.

Page 13, bottom: Chitosan solutions made with different powders and chitosan flakes.

Page 14, left: Two chitosan solutions both made with 50% v/v apple vinegar, 50% v/v water and 6% w/v chitosan powder: the left solution is made with Biorigins chitosan powder, the right solution is made with Oxford chitosan powder.

Page 14, right: Reaction chitosan with acetic acid [41].

Page 15: Testing the reactivity of the different chitosan solutions in lemon juice, apple juice, coffee kefir and sparkling water.

Page 16, center: Chitosan with yuzu juice resulting in cloudy mixtures, the chitosan is not dissolved.

Page 16, right: Electrical double layer and zeta potential [15].

## 5: FLAVOR DEVELOPMENT OF THE SHEETS

This research on SCF was started with carrot puree as the base material. Both during the M1.2 research project and M2.1 project, new flavors were developed which were different in texture (visible) and mouthfeel, but also in reactivity. The flavors developed during the M1.2 project were mostly overly fermented fruits and vegetables. During the M2.1 project, vegetable and fruit peels were fermented and further broken down with the addition of enzymes. For the M2.2 project, continuous experiments were done with: (overly) fermented fruit and vegetables; kombucha cultures (see chitosan solution – yuzu and kombucha); brewers' spent grain; peels; fruit and vegetable powders. To enable chefs to work with the basic recipes themselves, it is important to give them insights into the way that the recipe needs to be changed for different base materials. To give an indication of the use of powders instead of puree, the average water content of the experiments was measured (by weighing the silicone sheets with puree before and after dehydration). Based on this, the dry content (powder) and liquid content (solvent for additives and powder) were calculated. Other ingredients were evaluated on their nutritional content or even on their texture to improve the mouthfeel, foldability and reactivity of the sheets. An overview of the ingredients, methods and steps for further development can be found in Appendix B: Flavor developments.

In the evaluation session with the chefs of the development kitchen (as described in 'Dish Development'), twelve different sheets were evaluated on the texture, aesthetics and flavor to decide which flavor could fit a dish for the menu at Alchemist. The recipe with beetroot juice and cherry powder was chosen to develop the dish with, together with the carrot recipe, since this recipe was most developed and the sheets were showing the fastest reaction. The recipes of the sheets are described in 'The final recipe'.

Another flavor component of the sheets are the chitosan lines which were printed on top. As described in 'The chitosan solution', the chitosan was developed with apple vinegar. More tests were done with cherry vinegar and balsamic-plum vinegar. The results can be found in Appendix B: Chitosan experiments. Since the flavor perception did not change a lot when eating the sheets with these vinegars, the reaction time with both these vinegars was reduced and since the vinegars were very expensive to use (and to experiment with), the decision was made to continue with the apple vinegar for the final sheets.

Testing the final recipe of the beetroot-cherry sheets, the dissolvability of the sheets became apparent. The sheets dissolved in the reaction liquid, which resulted in a cannolo shape which diners would not be able to pick up with their hand. The carrot sheets did not dissolve at all, for this reason experiments were done with the beetroot-cherry puree with added carrot puree (a mixture with 25% carrot puree and 50% carrot puree were tested). Next to that, the reactivity was tested with less liquid (misting a plate with the liquid instead of a liquid in a bowl). The carrot-beetroot-cherry sheets reacted faster and even reacted quickly with less liquid,



resulting in sheets that hold their shape (Appendix B: Chitosan experiments) However, the sheets were less shiny and lighter in color. Since the dissolvability was dependent on the reaction liquid, for the final dish development, the sheets with 50%, 75% and 100% cherry-beetroot puree and 100% carrot sheets were all produced and evaluated for the final dish development (see 'Final dish development').

### PICTURES

Current page, middle: Edible paper sheets with different flavors; fermented purple carrot, sea buckthorn, carrot, spent grain with coffee, kombucha scoby.

Current page, right: Carrot sheets with balsamic-plum vinegar and cherry vinegar chitosan.

Page 18, top, left to right: Fermented unripe sea buckthorn; Sea buckthorn sheets; Kombucha scoby sheets.

Page 18, bottom left to right: Sheets made with spent grain and coffee; sea buckthorn, kombucha; and spent grain puree.

Page 19: Development of different beetroot-cherry purees.







## 6: SHAPING THE FOOD

### SHAPE DEVELOPMENT

For the shape and the shape-transformation of the sheets, some constraints were set. The final shape should be implementable in the kitchen context of Alchemist, which means reproducible for 48 guests on a daily basis. The chefs really admire the origami shapes, but the shapes were seen as time consuming and difficult to produce. The rolling-reaction of the sheets was seen as something really interesting and beautiful, with possibilities to implement it in the final menu. Several tests were done with laser-cutting the sheets in interesting shapes, butterflies were tested, since Alchemist is well known for 'butterflies', both in the menu and in the restaurant branding.

Although some research on SCF is available [5, 8, 14, 16, 34, 37] there are no guidelines available for making the patterns for specific shape transformations. When comparing similar flower shapes of the research of Z. Liu, et al. [16] with the research of Y. Tao [34], different patterns for the shape transformations are shown. For this reason it can be concluded that the patterns and transformations are dependent on the material.

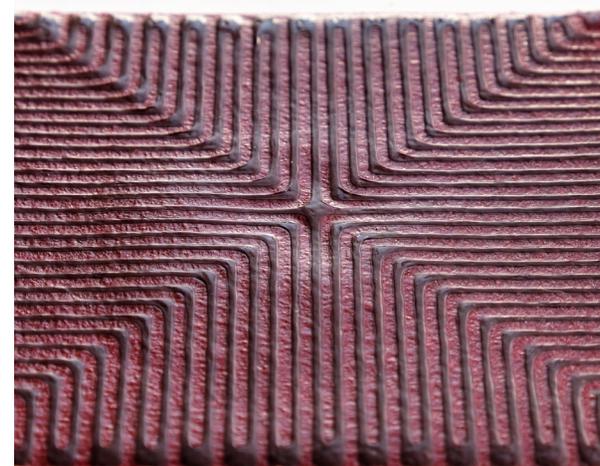
To find-out how the patterns should be developed for the shape-changing paper sheets, flowers with four petals were made from the striped sheets, two petals with horizontal stripes and two petals with vertical stripes. In reaction to a low-pH liquid, this resulted in



the reaction as shown in the pictures below.

Printing patterns were developed to laser-cut flowers with four petals, with vertical stripes in all four directions. In reaction to a liquid with a pH of 3.3, the four petals were all rolling up towards the middle. During the first evaluation session (see 'Dish development'), the chefs came-up with the first ideas; a flower or other circular shape, a dumpling or a larger cannolo. A second evaluation session was planned with the head-chef of development and the head-chef of research, in order to set a clear direction for the final shapes. In a short presentation (Appendix D, Session 2) the process and reaction of the flower was shown, an overview of other possibilities was presented and the following points were discussed to define the shape: the use of a laser-cutter; size (the printing platform of the food printer is limited to a maximum of 100 x 100 mm); size of the food on/in the transforming sheet; shape endings (round/ wide/ sharp). The rolling reaction (cannolo-shape) directly stood out as something that could be plated in a dish for the menu. A larger cannolo was preferred, according to the chefs this was more impressive in front of the guests. Other requirements were: it had to last at least two bites; it had to be possible to pick it up with one's hands; and it had to be filled with interesting flavor and texture combinations. While making some quick prototypes, it was decided that the shape had to be 60 x 80 mm, with sharp edges.

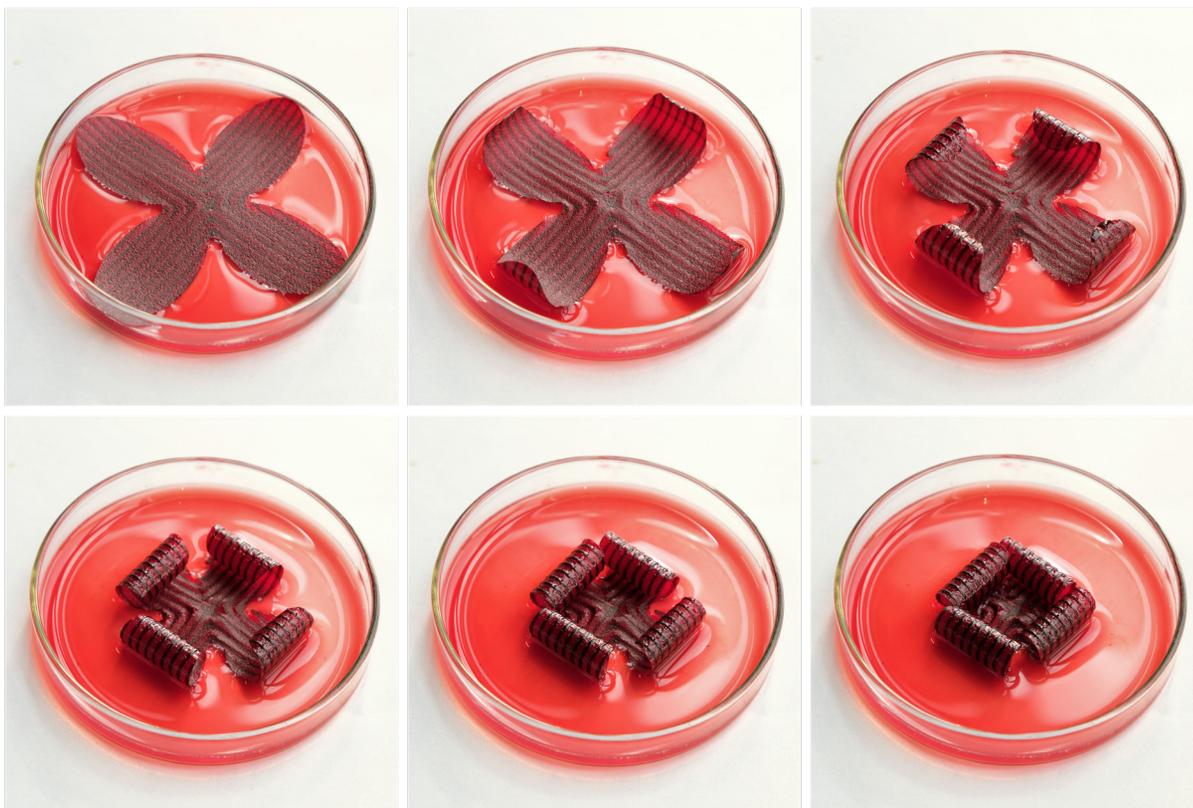
As a second option, a flower was discussed. The chefs



preferred a flower with more than four petals. This was the result of the conclusion that fewer petals gave a childlike impression. After this brainstorm session, three tartelette designs with twelve petals were developed. By visualizing these shapes and making them tangible by laser-cutting them out of sheets, the chefs were having a clear preference. This resulted in the printing pattern that was used for later iterations.

### PATTERN DEVELOPMENT

When 3D printing with food, no support material is available. The chitosan solution is a thin solution, which means that almost no pressure is needed to print and as soon as the liquid comes out, a good retraction of the liquid is hard to achieve. Because of this, the travel route of the printer should not cross the chitosan patterns, since this can influence the direction of shape-transformation. To develop the striped printing pattern, a square was made with the size of the outlines (using Autodesk Fusion 360), this pattern was extruded in 3D, and the number of lines was controlled by increasing/ decreasing the percentage of aligned rectangular infill pattern (Slic3r). It was observed that for the circular flower patterns, petals with vertical stripes were



needed. No standard infill pattern is available to create those stripes, these patterns had to be developed and adjusted in the programs Adobe Illustrator, Autodesk Fusion 360, Slic3r and Repetier Host. The use of these programs to create the chitosan printing patterns is explained below.

#### *Adobe Illustrator*

Adobe Illustrator is used to create the line patterns for 3D printing and also the patterns for laser-cutting / engraving the final shapes. Several pattern explorations can be found on page 22. For the pattern, it is important to set the line thickness to 0,4 mm which can be extruded in Fusion360 afterwards. Furthermore it is

important that the lines are connected, to create continuous paths for printing. However, when there are multiple lines coming together in one point, this often leads to larger drops of chitosan, which can influence the reactivity and even the mouthfeel of the sheets. These constraints should be taken into account when designing the patterns.

#### *Autodesk Fusion 360*

Autodesk Fusion 360 is used to convert the 2D patterns into 3D shapes by extruding the 2D pattern. This conversion is only possible if the pattern is fully connected (it is not possible if the pattern contains separate lines). The svg file is converted into a stl file.

#### *Repetier Host / Slic3r*

The program Slic3r can be used separately or as part of the program Repetier Host. The stl file can be opened in the program Repetier Host, in which Slic3r is used to slice the pattern in layers. Within Slic3r, the patterns are sliced according to the constraints in the settings. For printing with this thin chitosan solution, the printing speed can be set to quite high (50 mm/s), the layer height is set to 0,4 mm and the layer thickness to 0,3 mm. The seam position should be set to 'aligned' and crossing parameters should be avoided. For the printer settings, a custom g-code should be used to remove additional extrusion before printing, since this is not needed (and will be too much) with the chitosan which only needs low pressure to print. Despite the use of the settings, the travel route often crosses the design. This travel path can be visualized in Repetier Host, and changed by changing the x and y coordinates of the travel path in the gcode. The final gcode for the tartelette can be found in Appendix E: 3D printer.

#### *Laser-cutting of the printed patterns*

The final shapes will be cut-out of the chitosan printed sheets. Straight edges of printed shapes can be made using a sharp utility knife, but for complex rounded shapes, like the tartelette, the results will become more precise when a laser-cutter is used. The shapes are transferred to the program Glowforge [7], which is part of the Glowforge laser-cutter. In this program, the platform with the material is analyzed and the digital shape can be placed in the correct spot on the platform. The chitosan lines make this process more complex, since the lines need to be straight inside the shape (instead of e.g. diagonal), as this can influence the shape-transformation. For dark materials, the lines are difficult to visualize on the projection. For this reason, light colored sheets are preferred (carrots instead of beetroot sheets). In the program, the speed, power and material thickness for both laser-cutting and engraving can be set. The settings as used for

the Glowforge laser-cutter and the final laser-cutting tartelette file can be found in Appendix E: Laser-cutter.

#### TARTELETTE ENGINEERING

For the tartelette, several sizes were tested and developed. First without the chitosan pattern, as quick prototypes to choose the final shapes and settings. For the outlines of the tartelette laser-cutting is used. Engraving is used on the folding lines, a circle of 40 mm diameter on the side with the chitosan pattern to create a folding transformation instead of rolling-up. When testing, as soon as the petals touched the reaction liquid, the sheets still started to roll instead of fold. An explorative process resulted in a wet 45 mm circle below the tartelette, and a 38 mm circle inside the tartelette. The 38 mm circle shape was slightly smaller than the engraving, which resulted in petals that could bend along the 38 mm circle. The 45 mm circle was slightly larger, giving the possibility to exactly place the tartelette on top of this circle. This way, the edges of the petals were not touching any liquid and the petals were able to bend along the engraving. Since circles of different sizes were quickly cut out of plastic, an edible alternative still had to be developed. Thin crackers were made to place below and inside the tartelette as alternatives for the plastic circles.

.....

#### PICTURES

Page 20, bottom: Shape transformation with chitosan stripes in horizontal and vertical direction on the flower petals.

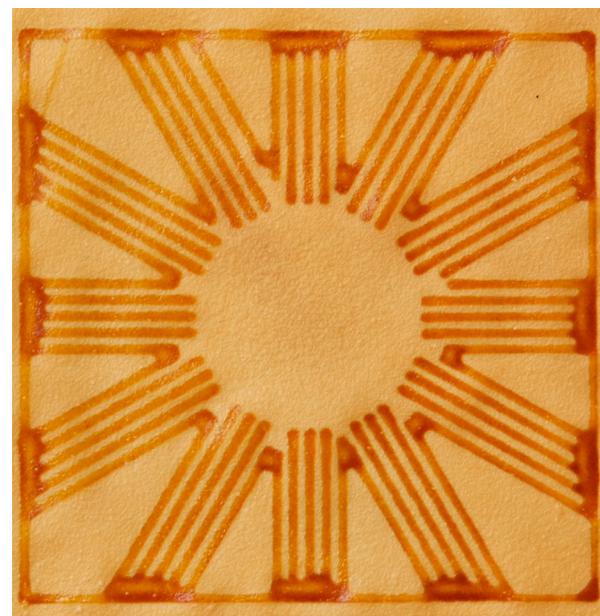
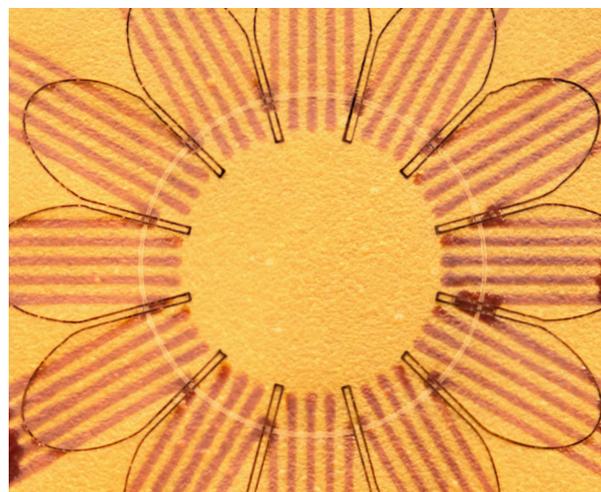
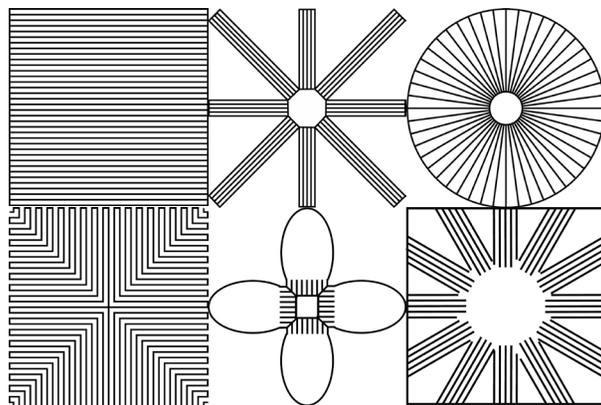
Page 20, top: Printing pattern for flowers with four petals, vertical chitosan lines in all directions.

Page 21: Shape-transformation of beetroot-cherry flowers.

Current page, top left: Pattern explorations for 3D printing.

Current page, top right and center left: 3D-printing and laser-cutting pattern of the tartelette.

Current page, bottom: Tartelettes with plastic circles on top and below.



## 7: DISH DEVELOPMENTS

Most of the development of this project has taken place within Alchemist. Because of that, everyday feedback and input was given by the chefs and researchers while talking about the work and developments. As mentioned in 'Flavor development', as soon as some of the new developed flavors were showing a consistent reaction at the restaurant, an official brainstorm session was organized with Head of Development Theis Brydegaard, two chefs of the development kitchen, Head Chef Rasmus Munk, Head of R&D Diego Prado and design researcher Maggie Coblentz (MIT). The session was structured as followed:

1. A short presentation about the developed material, explaining the preparation methods of the edible paper sheets, the chitosan solution and the shape developments (Appendix D: Session 1). The chefs were informed about the constraints and possibilities of the material, e.g. how the chitosan had to be dissolved, the optimum pH of the reaction liquid and the dehydration time.
2. Printed sheets were plated with ingredients from the kitchen (mussels, tomatoes, herbs) to show the shape-transformation and visualize a possible dish. Several reaction liquids were used (apple juice, blueberry kombucha, tomato juice, lemon juice, for pH see Appendix B: pH), to give an indication of the sourness of the reaction liquid.
3. Twelve different paper sheets (made with different base ingredients) were presented and compared on flavor, texture, aesthetics and reaction speed.
4. A first brainstorm on the possible dish combinations.

The recipe with beetroot juice and cherry powder was one of the favorites from the start, the shininess and color of the sheets was the aspect which first

stood out. Also, this combination had the best mouthfeel and flavor during the tasting. For possible dish combinations, a salty combination was theorized, licorice was mentioned as something traditionally Danish to combine with beetroot and in the same way, rose, shrimps, berries, balsamic and duck stood out. This process included the research of well-known beetroot and cherry dishes of other high-end restaurants, as great examples on how to plate and combine ingredients. The Flavour Thesaurus by Niki Segnit [28] is a book used in many restaurants for ideas on pairings of ingredients, suggestions from this book on pairings of beetroot, cherry and carrots can be found on page 24. Furthermore, the location of serving the dish had already been considered. The chefs quickly concluded that this dish, since it was impressive with the shape-transformation, had to be served in the dome (in the lounge, only snacks are served, in the dome dishes and desserts are served, on the balcony sweets with coffee and tea are served).

When more of the beetroot-cherry sheets were developed, a second evaluation session was organized with Diego Prado and Theis Brydegaard, to define a clear direction for the final shapes (see 'Shape developments') and to discuss the flavor combinations. Theis Brydegaard came up with the idea of filling the paper sheets with dehydrating beetroots, soaking them afterwards in beetroot juice and bake them in butter with salt. For the tartelette a savory panna cotta filling was discussed.

A third session was planned to work together on the development of the final dish. Beetroot cherry sheets of 60 × 80 mm were prepared and strips of the dehydrated beetroot were covered with cherry powder. A cream was made with nutritional yeast to cover the beet with some creamy white drops. Morel consommé was used as the reaction liquid. While testing the constructed dish, the beet did roll up, but only towards the beetroot strip, instead of covering the beetroot strip. Testing this multiple times, with different sizes of



beetroot-cherry sheets, the same reaction was shown consistently. Positively, the beet did not dissolve in the morel consommé, which can be caused by the higher pH of the consommé (pH 5).

Sheets with 50% beetroot, 50% carrot puree and sheets with 75% beetroot and 25 % carrot puree were tested as well and resulted in a similar reaction as the 100% beetroot-cherry puree. Also, carrot sheets were tested to compare their reactivity. The carrot sheets covered the filling, exactly as the transformation which was aimed for.

Since the shape was the most special part of the dish, the decision was made to continue with the carrots sheets and make a similar carrot dish: carrots were cooked until soft, dehydrated until crunchy, cooked in carrot juice with butter and baked in butter with salt to create a crunchy salty outside and chewy inside. The carrot juice was made from fresh carrots, the leftover carrot pulp was dehydrated as well to create a carrot powder and the cooking water was reduced to a thick caramel as base for a cream. Also, as a red-colored alternative to the beetroot sheets, a carrot puree was made for which the additives were dissolved in beetroot juice. This resulted in a red puree, giving the possibility to make the beetroot dish as well with red carrot-beetroot sheets and to use this puree for red tartelettes.

The tartelette was further developed and tested with a panna cotta on the inside. As soon as the petals touched the reaction liquid, the sheets started to roll instead of fold. An explorative process, as described in 'Shape development', resulted in a wet 45 mm circle cracker below the tartelette, and a 38 mm cracker inside the tartelette. The 45 mm cracker had a wet apple gel layer on top. As soon as the tartelette touched this wet layer, the petals of the shape folded along the 38 mm cracker. The hardness of this material also provided the possibility to pick-up the dish by hand, which was not possible with only a panna cotta



inside.

The final dishes presented were made with the carrot-sheets and the red carrot-beetroot sheets. More research is needed to make the beetroot-cherry sheets transform in a similar manner. As recently researched by F. Chen et al., [5] the thickness of the sheets and pattern (line) density can be interesting directions to look at using this material. However, since the visible reaction is consistent, the material can already be implemented for different shape-transformation, e.g. the flower shown on page 21. For this reason, both the cherry-beetroot, carrot and red-carrot-beetroot purees are described in 'The final recipes'.

CARROT	BETROOT	CHERRY
Anise	Walnut	Almond
Apple	Anchovy	Banana
Beef	Capers	Chocolate
Cabbage	Apple	Cinnamon
Cardamom	Beef	Coconut
Celery	Chocolate	Coffee
Cinnamon	Coconut	Goat's Cheese
Coconut	Goat's Cheese	Hazelnut
Cucumber	Horseradish	Lamb
Cumin	Liver	Peach
Hazelnut	Oily Fish	Smoked Fish
Olive	Onion	Vanilla
Onion	Orange	Walnut
Orange	Pork	
Parsley	Potato	
Peanut	Watercress	
Swede		
Walnut		

#### PICTURES AND FIGURES

Page 23: Brainstorm sessions with chefs and researchers at Alchemist.

Current page, top right: Suggestions from the book *The Flavour Thesaurus* by Niki Segnit [28], ingredient pairings with beetroot, cherry and carrot.

Current page, top centre: Comparing the reactivity of the sheets with morel consommé and apple juice.

Current page, centre: Laser-cutting crackers in 38 mm and 45 mm circles.

## 8: THE FINAL RECIPES

Below the final recipes can be found for the dishes developed at Alchemist. The beetroot-carrot tartelette will be put on the menu of Alchemist, for which certain dish components will be adjusted. The current cracker is not completely flat and even the apple gel creates a height difference, resulting in different reactions of the tartelettes. Research on a flat cracker and a thinner gel will be done in collaboration with the development chefs in the development kitchen.

### SHAPE-CHANGING PAPER SHEETS

#### INGREDIENTS

- *Carrot sheets*
  - 1 kg fresh carrots
  - 10,8 g algin
  - 0,9 g agar
  - 0,9 g carboxymethylcellulose
  - 7,2 g wheat starch
  - 27,0 g glycerin
- *Carrot-beetroot sheets*
  - 1 kg fresh carrots
  - 10,8 g algin
  - 0,9 g agar
  - 0,9 g carboxymethylcellulose
  - 7,2 g wheat starch
  - 27,0 g glycerin
  - 315 ml beetroot juice
- *Beetroot-cherry sheets*
  - 100 g fine cherry powder
  - 925 g beetroot juice
  - 8,2 g algin
  - 0,7 g agar
  - 0,7 g carboxymethylcellulose
  - 5,5 g wheat starch
  - 20,6 g glycerin

- *Chitosan solution*
  - 100 g Carlsberg apple-vinegar
  - 100 g water
  - 12 g Oxford Vitality chitosan powder

#### EQUIPMENT

- Laser cutter (the patterns and settings for the Glowforge laser-cutter can be found in Appendix E)
- Food printer with syringes (the gcode for the Wiiibox Sweetin foodprinter can be found in Appendix E)
- High-speed blender (e.g. thermomix)
- Silicone baking sheets 180 × 160 mm
- Stencils for 120 × 120 mm paper sheets, with a thickness of 1 mm (laser-cutter pattern can be found in Appendix E)
- Spreader/ plastering knife with a minimal length of 20 cm
- Fine-mesh sieve
- Food dehydrator
- Cutting-mat, sharp utility-knife, ruler and paper tape



## METHOD

### *Carrot puree / carrot-beetroot puree*

1. Peel the carrots and cut them into chunks of about 10 mm.
2. Place the carrot chunks in a large pan and cover them with water.
3. Bring the water to a boil and cook the carrots over medium heat until they are soft and you can mash them with a fork.
4. Drain the carrots, but save the boiling water.
5. Measure 900 grams of boiled carrots and blend them in a high-speed blender.
6. Add the agar, CMC, and algin with 300 ml of the boiling water of the carrots or 300 ml beetroot-juice to a saucepan and bring to a boil, keep stirring until the powders are fully dissolved.
7. Add three tablespoons of cooled down boiling water or beetroot juice to the starch, mix to dissolve and add together with glycerol, dissolved agar, CMC and algin to the blender.
8. Blend on the highest speed, until the puree is very smooth.
9. Pass the puree through a fine-mesh sieve and leave to set overnight in the fridge.

### *Beetroot-cherry puree*

1. Add the agar, CMC, and algin with the beetroot-juice to a pan and bring to a boil, keep stirring until the powders are fully dissolved.
2. Add three tablespoons of beetroot juice to the starch, mix to dissolve and combine with glycerol, dissolved agar, CMC, algin and cherry-powder in a

high-speed blender.

3. Blend on the highest speed, until the puree is very smooth.
4. Pass the puree through a sieve and set overnight in the fridge.

### *Chitosan solution*

1. Mix the chitosan with the water.
2. Add the vinegar and mix until the powder is dissolved.
3. Leave the chitosan-solution overnight in the fridge, this will thicken the solution and reduce the amount of air-bubbles.

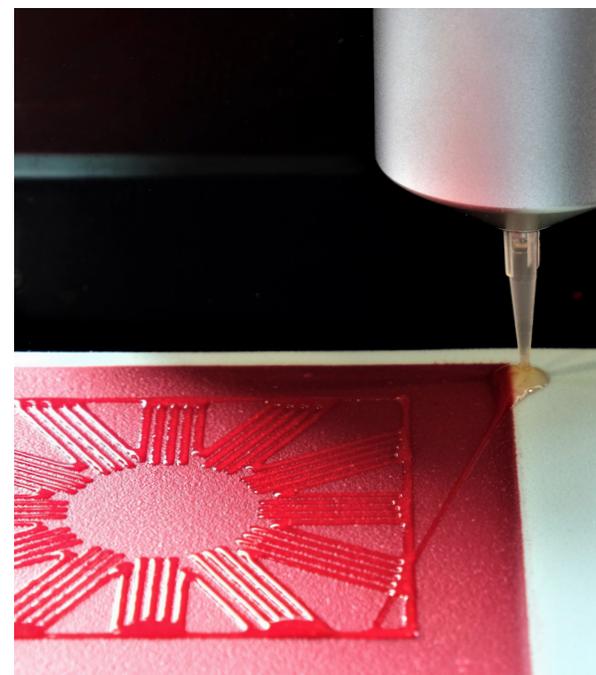
### *Shape-changing sheets*

1. Place the stencils on top of the silicone sheets and put two tablespoons of puree on top of each sheet.
2. Spread out the puree with the spoon and use the plastering knife to create an even layer of puree by spreading over the stencil.
3. Take off the stencils and dehydrate the silicone sheets with the puree in a dehydrator at 40 Degrees Celsius. Take the sheets out as soon as they are dry to the touch, regularly check (every 15 minutes) after the sheets have been in the dehydrator for 45 minutes.
4. Fill a printer-syringe with the chitosan-solution.
5. Print the pattern (tartelette or stripes) with the chitosan solution on the dehydrated sheets.
6. Place the sheets in the dehydrator again, at 40 Degrees Celsius. Take them off of the silicone when the chitosan solution is dry to the touch (this will take around 30 minutes).

7. Leave the printed sheets to dry in the dehydrator for five more hours.
8. The printed sheets need to dry four more days on air to reach the optimum reactivity.

### *Cutting the sheets with striped pattern*

1. Use the cutting mat, ruler and utility knife to cut the sheets, first cut the sheets along a first chitosan-stripe, while using the ruler (for the reactivity it is important that the chitosan-strips are as close as possible to the borders of the sheet).
2. Measure the width of 6 cm and cut along the second line.
3. Measure the length of 8 cm and cut perpendicular on the lines.



### Laser-cutting the sheets with the tartelette pattern

1. Place the sheet, with the shiny side upwards, in the laser-cutter.
2. Connect the sheets with paper-tape to (a clean) laser-cutting platform.
3. Open the laser-cutter application on a connected device.
4. Open the laser-cutter tartelette file and circle.
5. Autofocus the laser-cutter on the sheet.
6. Move the shape-outlines exactly on top of the printed pattern, set the circle to the same x and y coordinates as the coordinates of the shape-outlines.
7. Change the setting of the circles to engrave and the settings of the shape-outlines to cut.
8. Laser-cut/ engrave the file.



### SHAPE-CHANGING CANNOLO

Two varieties are made with the shape-changing cannolo, one orange with carrots and one purple with beetroots. The carrots are filled with chewy carrot strips and the beetroots with chewy beetroot strips. Both varieties are explained in this recipe.

#### INGREDIENTS

- *Shape-changing sheets*  
Carrot- and/or carrot-beetroot-sheets with a striped chitosan pattern, see previous recipe (beetroot-cherry sheets with a striped chitosan pattern can be used as well, but will show a different reaction, as shown on page 21).
- *Carrot strips*  
3 kg carrots  
300 g butter  
Mussel-powder  
Sea-salt
- *Beetroot strips*  
1 kg beetroots  
300 g butter  
Cherry-powder  
Sea-salt
- *Vegetable juice*  
30 g lemon juice  
1300 g green tomato  
1200 g green apples  
950 g green strawberries  
18 g wheat grass  
300 g green apple Boiron
- *Yeast cream*  
2 egg whites  
2 dl rapeseed oil  
3 tablespoon yeast flakes  
½ lemon (juice)  
Salt and pepper

- *Serving*  
Rape blossom  
Ramson capers  
Lilac

#### EQUIPMENT

- Juicer
- Dehydrator
- Fine mesh nylon strainer
- High-speed blender
- Juicer
- Centrifuge
- Squeezy bottles

#### METHOD

##### *Chewy beetroot strips*

1. Wash the beetroots, bring them to a boil in a pot with enough water to cover them.
2. Reduce the heat and let them simmer on low heat till they are fully soft, even from the inside (regularly check with a toothpick or fork).
3. Drain the beetroots, but save the boiling water.
4. Cover the beetroots with some cold water, and rub the skin off of the beetroots (directly after cooking it will be easiest to do so).
5. Cut the beetroots into lengthwise strips with a diameter of 1 cm.
6. Dehydrate the strips in the dehydrator on 40 degrees, until they are fully dried (crunchy).

7. Add the dried beetroot strips to a pot and bring them to a boil with beetroot juice (fresh or ready to use bottles) and 200 grams of butter. Reduce heat and simmer for two hours, add more water or juice if needed (the beetroots should be fully covered with liquid).
8. Drain the beetroot strips, the flavorful beetroot-butter liquid can be reduced together with the boiling water to create a pink caramel.
9. Fry the strips in a pan with 100 grams of butter with a pinch of salt till they become dark colored and crunchy.
10. Drain the strips on paper towels and cut the strips in smaller strips of 6,0 x 0,5 x 0,5 cm.
11. Before use, cover the strips with cherry powder.

*Chewy carrot strips*

1. Wash the carrots, peel them and bring 1 kg of the carrots to a boil in a pot with enough water to cover them.
2. Reduce the heat and let them simmer on low heat till they are fully soft, even from the insight (regularly check with a toothpick or fork).
3. Drain the carrots, but save the boiling water.
4. Cut the carrots lengthwise in half, when using large carrots cut in quarter lengthwise.
5. Dehydrate the carrots in the dehydrator on 40 degrees, until they are fully dried (crunchy).
6. In the meantime, juice the leftover (2 kg) or carrots with a juicer.
7. Save the juice and spread-out the carrot-pulp in the dehydrator and dry on 40 degrees.



8. Add the dried carrot strips to a pot and bring them to a boil with the fresh carrot-juice and 200 grams of butter. Reduce heat and simmer for two hours, add more water or juice if needed (the carrots should be fully covered with liquid).
9. Drain the carrot strips, the flavorful carrot-butter liquid can be reduced together with the boiling water to create an orange caramel.
10. Fry the strips in a pan with 100 grams of butter with a pinch of salt till they become golden-brown and crunchy.
11. Drain the strips on paper towels and cut the strips in smaller strips of 6,0 x 0,5 x 0,5 cm.
12. Blend the dehydrated carrot-pulp in a high-speed blender to create a powder. Pass through a fine mesh sieve.
13. Mix the carrot powder with the mussel powder

(add one spoon at a time and taste too your liking, it will get a salty, fish aroma).

14. Before use, cover the strips with the carrot-mussel powder.

#### *Yeast cream*

1. Mix egg whites, lemon, pinch of salt and pepper and mix with a hand blender.
2. Slowly add oil to create a mayonnaise texture.
3. Add yeast flakes. Add salt, pepper and lemon juice to taste.

#### *Green tomato juice*

1. Juice all ingredients and strain through a fine mesh nylon strainer.
2. Add 300 g of green apple Boiron to 2000 ml of

juice.

3. Centrifuge for 30 minutes at 4700 rpm.

#### *Serving*

1. Place a carrot/beetroot-carrot sheet in front of you with the shiny, chitosan-side downwards, with the stripes in horizontal direction.
2. Place a beetroot/carrot strip (covered with the powder) lengthwise in the middle (perpendicular to the striped pattern).
3. Add 6 dots of the yeast cream on top and cover with some ramson capers and flowers (lilac for the beetroot, rape blossom for the carrot).
4. Cover the plate with a layer of vegetable juice.
5. First serve the plate and place the sheet with a small spatula on top in front of the guests.





## SHAPE-CHANGING TARTELETTE

### INGREDIENTS

- *Shape-changing sheets*  
Carrot or carrot-beetroot or beetroot-cherry sheets with a tartelette pattern.
- *Cracker*  
500 g wheat flour  
20 g sugar  
10 g salt  
180 g water  
85 g olive oil
- *Apple gel*  
300 ml apple juice  
3 g xanthan gum
- *Cabbage emulsion*  
80 g caramelized spring cabbage  
70 g egg white  
6 g pear vinegar  
10 g zested horseradish  
150 g rapeseed oil  
Salt and pepper
- *Oyster panna cotta*  
175 g crème fraîche  
70 g Philadelphia (cream cheese)  
10 g horse radish  
60 g oyster  
2 gelatin leaves  
Salt and pepper
- *Serving*  
Purple sweet alyssum  
White lilac  
Chef selection caviar

### EQUIPMENT

- Vacuum sealer (suitable for liquids)

- Hand blender
- Fine mesh, nylon strainer
- Ring-shaped molds, 3 cm outer diameter, 1 cm inner diameter
- Pasta machine
- Laser-cutter (patterns can be found in Appendix E) or round cookie cutters, 4,5 cm diameter and 3,8 cm diameter

### METHOD

#### *Cracker*

1. Mix all ingredients and cool down for one hour.
2. Roll the dough on a pasta machine.
3. Punch out with a cookie cutter or laser-cut the circles after baking. Bake at 170 degrees Celcius for 20 minutes, until golden brown.

#### *Apple gel*

1. Add the xanthan gum to the apple juice and mix it with a hand blender.
2. Pass the gel through a fine mesh strainer.
3. Put the gel in a large container and place under vacuum to get rid of the air-bubbles.
4. Add the gel to a squeeze bottle and store in the fridge till use.

#### *Cabbage emulsion*

1. Add the caramelized spring cabbage, egg white, pear vinegar and zested horseradish to a 1-litre measuring cup. Use a hand blender to mix thoroughly.

2. Add the oil while blitzing with the hand blender. Aim for a mayonnaise-like texture. Add salt, pepper and lemon juice to taste.
3. Strain through a fine mesh strainer.
4. Let the emulsion rest for 1 hour. Check the texture, add some water if the emulsion is too thick.

#### *Oyster panna cotta*

1. Blitz all components, be careful not to split it.
2. Add salt and pepper to taste and leave to infuse for 10 minutes.
3. Set with 2 leaves of gelatin, strain through a fine mesh strainer, spread into the mold and freeze.
4. When frozen, take out of the mold.

#### *Caviar*

1. Weight the caviar in portions of 3 grams.

#### *Serving*

1. Add a layer of apple gel (create a spiral shape with the squeeze bottle) on top of the largest cracker.
2. Place the cracker with apple gel on a plate.
3. Pre-fold the tartelette petals on the engraved circle and press the petals down again afterwards (if needed, put something heavy on top).
4. Place the panna cotta ring on top of the smaller cracker (38 mm).
5. Fill the panna cotta ring with the cabbage emulsion.
6. Place a portion of caviar on top.
7. Use a squeezer to add the flowers on the caviar (at

least 3 of each kind).

8. Place the tartelette shape in front of you with the shiny, chitosan-pattern facing downwards.
9. Place the small cracker with the toppings in the middle.
10. First serve the plate with the cracker with apple-gel and place tartelette with a small spatula on top in front of the guests.

.....

#### PICTURES

Page 25: Using stencils to spread out the carrot and beetroot-cherry puree with a thickness of 1 mm.

Page 26: 3D printing the tartelette pattern.

Page 27: Laser-cutting a carrot tartelette.

Page 28, top left: Cooking carrots for the carrot strips.

Page 28, top right: Cooking dehydrated carrots in butter and carrot juice.

Page 28, left center: Frying the beetroot strips in butter (after boiling in beetroot-juice and butter).

Page 28, right center: Fried beetroot strips.

Page 28, bottom left: Carrot pulp before dehydration.

Page 28, bottom right: Fine cherry powder.

Page 29, left: Beetroot-carrot sheet with a beetroot strip, yeast cream, ramson capers and flowers.

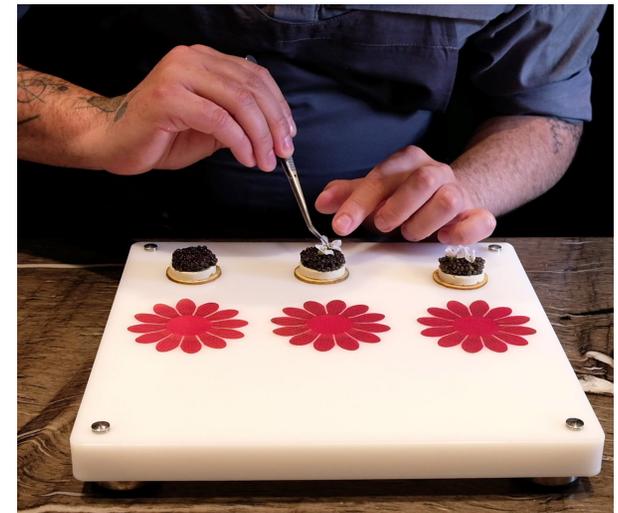
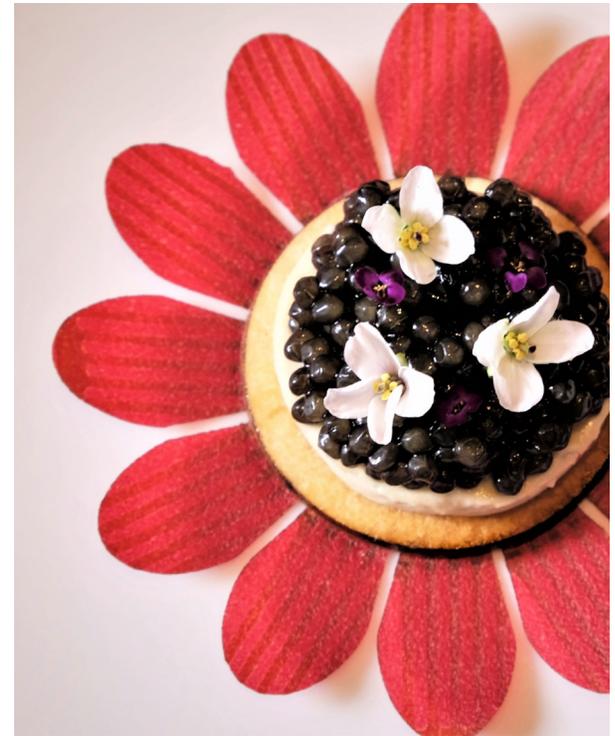
Page 29, right=: Beetroot-carrot sheet transforming in vegetable juice.

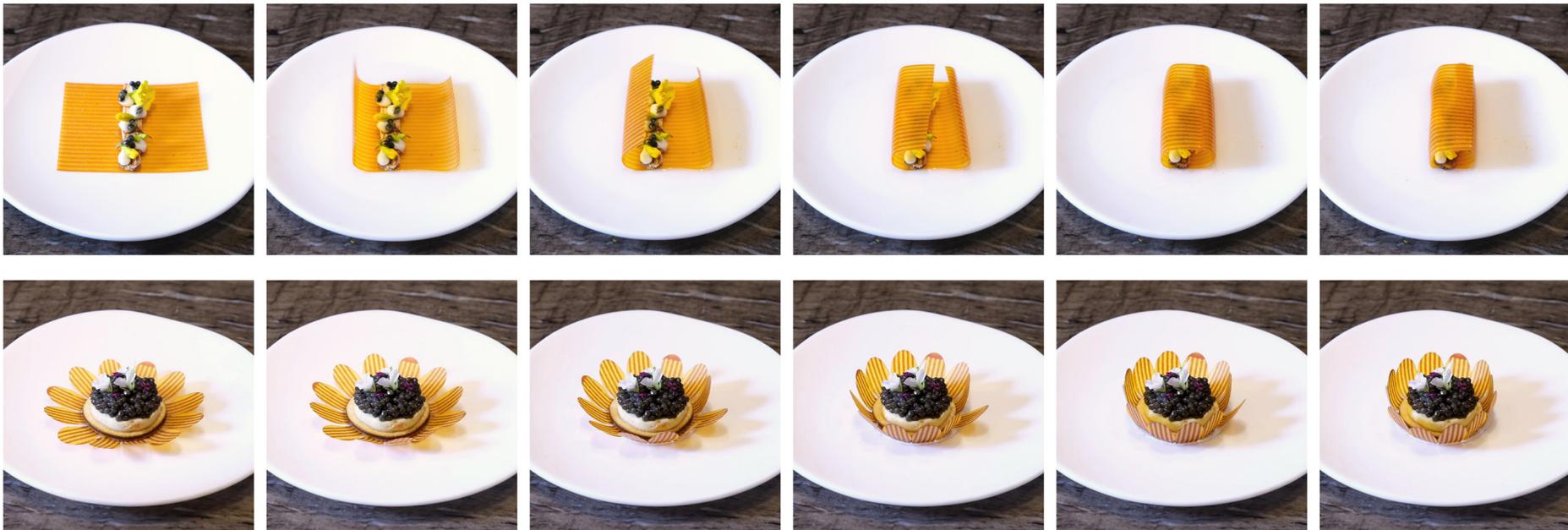
Page 30: Plating a carrot sheet with carrot-strips, yeast cream, ramson campers and flowers.

Current page, bottom: Plating a tartelette with a panna cotta ring with the cabbage emulsion (left), caviar (center) and flowers (right).

Current page, top right: The final beetroot-carrot tartelette with a cracker, panna cotta, cabbage emulsion, caviar, white lilac and purple sweet alyssum flowers.

Next page: Transformation of the carrot sheets and carrot tartelettes.





## REFLECTION

Starting my final master project, I continued another semester with the shape-changing food without knowing if the material was becoming reactive at all, which was challenging. Taking a different approach, analyzing and measuring all the possible influencing factors systematically (instead of a research through design approach which I often apply in my work), enabled me to define the appropriate preparation method to create the transformative material. For me it was a learning process to keep track of all the data and to analyze the results, a process which enabled me to reason my choices and take the next steps at the Alchemist restaurant.

Working with the chefs in their restaurant was a dream come through. My favorite days were the days in the development kitchen, working between the development chefs, talking about the food and material developments and regularly tasting and evaluating components for new dishes. Although I often was seen as a chef when working there, I started to understand my value as a designer in this Michelin-starred venue. Developing a dish together with the head-chef of the development kitchen, was a process in which we were able to complement each other. With my understanding of food, chemistry and design, we could discuss if the ingredients or the printing patterns needed to be adjusted to improve the reactivity or to improve the esthetical value of the dish. With my chemistry background I understood how to change the pH of the sauces when needed and I was able to explain the material behavior to the chefs. This collaboration is something that triggers me, I would love to continue with this work. Also, I would love to further develop myself as a chef. I see that I can differentiate myself as designer with the knowledge I have gained the last years working in the kitchen and experimenting with fermentation techniques. This enables me to communicate with chefs on a certain level. This year I started with the Food Future Academy, an online



culinary school for plant-based cooking. This education contributes to my sustainable vision and provides me with more knowledge of ingredients, more confidence in the kitchen and enables me to support chefs in the development section even better.

Alchemist is a restaurant in which scientists, designers and chefs come together. Doing this project, I gained a better understanding of the material by diving into the chemistry of the chitosan solution. Working with PhD candidate Nabila Rodriguez (PhD in gastronomy and science, Harvard and Basque Culinary Centre) at Alchemist, helped me to create this understanding and argument decisions accordingly in the process. With my background in Food Technology (at the Wageningen University), I was able to understand research publications on chitosan and write about the relevant information for my report. I enjoyed working with Nabila Rodriguez and I am planning to set-up future collaborations to continue implementing science while doing material research. Implementing these aspects in my work, enables me to publish in 'The Journal of Gastronomy and Food Science', a research journal which is read by many chefs and scientist. Currently I am working on the publication of the M1.2 paper together with Miguel Bruns and PhD candidate Ferran Altarriba for TEI 2022. The next step with this M2.2 report is to structure the content, to set-up sensory analyses and to rewrite it for the upcoming special issue on 'The Future of Human-Food Interaction' in 'The Journal of Gastronomy and Food Science'. Even for Alchemist it is important to share research content on the dishes or ingredients they serve in the restaurant, being an example for other restaurants and supporting other chefs to take new step in the world of gastronomy. Businesswise, this can even open opportunities for me to support more restaurants with their own unique food experience.

Throughout the project, digital manufacturing techniques were implemented. At Alchemist the laser-cutter was already used for several dishes, but although

there were food printers in the restaurant already, it was something Alchemist did not implement in their daily practices yet. With the development of the shape iterations and final tartelettes, I developed myself in creating the new double layered chitosan-patterns. I learned how to adjust the travel path of the printer by changing the coordinates. This was needed to create the most efficient, aligned printing paths, which is necessary for printing a chitosan solution without support material and with limited retraction. I started using illustrator as part of the 3D design process and for the laser-cutting files. I confidently found a way of working with the different programs as described in 'Shape development' of the report, which enabled me to visualize ideas quickly and ask for feedback of the chefs. It also enabled me to utilize that part of me which strives for perfection, which is what I was aiming for in the development of the final shapes. Developing these skills will be beneficial for the further development of this material, but also for new research projects and collaboration I am planning to work on.

Having my own startup enabled me to travel to Denmark and set-up the collaboration with Alchemist. Although the start-up is focused on food-printing, this project initially was not focused on developing my entrepreneurial skills. However, because of setting up this collaboration and creating an understanding of my value as designer in this industry, new opportunities were born to continue with. I still don't know in how far I will directly continue with Upprinting Food and the team. However, I found out that I don't want to work on management, scaling and production processes, but that I want to continue working on innovative (research) projects, related to digital manufacturing techniques, human food interaction and sustainability. Since the Scandinavian hospitality industry, with restaurant as Alchemist and Noma, is seen as example for many chefs in the Netherlands, the first Dutch food labs are currently in development. These are labs in which the Dutch food culture will be explored, new techniques

are materials are researched and workshops or research outcomes are provided to chefs to implement in their restaurant. I further developed my network and interest of chefs through the collaboration with Alchemist, and I will continue working on several related projects, among others with the Low Food Lab (by Michelin chef Joris Bijdendijk), Het Smaakpark, Foodlab Manenwolfs and if possible with students and professors in the new food squad at the Industrial Design faculty at the TU/e.

.....  
PICTURE

Page 34: Carrot tartelette.

## CONCLUSION

This project started with the goal to create a consistent shape-changing material, something which is needed when the food has to be served on a daily basis in a world-class restaurant to 48 guests. This process took place in the Netherlands and included many measurements and analyses. Since this is a new shape-changing material and the outcomes were unknown, every step had to be repeatable and the (non) influencing factors on the reactivity of the material had to be defined. The most important factor turned out to be the dehydration time of the material, in which a clear development of the reactivity was shown.

The next steps were taken at the Alchemist restaurant in Copenhagen. The developed process had to be tested in the restaurant, the differences between the vinegars and chitosan powders had to be compared, new flavors and shapes were created and brainstorm sessions with the chefs were organized to set a direction for dish development. The project is finalized with new shapes, flavors and two dishes (including their flavorful components), but most of all a better understanding of the materials and its properties. There are multiple directions for further development of the food, new research projects and collaborations with restaurants. With this project, the first collaboration is shown on transforming food research within a restaurant context, in which the material is developed with the chefs, enabling them to integrate it in their own creative process. Although still more development is needed before the dish is put on the menu at Alchemist, by showing this process and the potential, the first step has been made in reducing the bridge between human food interaction and gastronomy design.

.....  

## PICTURES

Serving the beetroot-carrot tartelettes.



## REFERENCES

- [1] AH, Biologisch Natuurazijn [online]. 2020 [Accessed 20 March, 2021]. Available from <https://www.ah.nl/producten/product/wi101200/ah-biologisch-natuurazijn>
- [2] F. Ahmadi, Z. Oveisi, S. Mohammadi Samani, Z. Amoozgar. Chitosan based hydrogels: characteristics and pharmaceutical applications. *Research in pharmaceutical sciences*, 2015, 10.1: 1.
- [3] Ferran Altarriba Bertran, Samvid Jhaveri, Rosa Lutz, Katherine Isbister, and Danielle Wilde. 2019. Making Sense of Human-Food Interaction. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19). Association for Computing Machinery, New York, NY, USA, Paper 678, 1–13. DOI:<https://doi.org/10.1145/3290605.3300908>
- [4] Byflow, 3D food printing [online]. 2021 [Accessed 1 June, 2021]. Available from: <https://www.3dbyflow.com/company>
- [5] Fengying Chen, Min Zhang, Zhenbin Liu, Bhesh Bhandari. 4D deformation based on double-layer structure of the pumpkin/paper. *Food Structure*, 2021, 27: 100168.
- [6] Bin Gao, Qingzhen Yang, Xin Zhao, Guorui Jin, Yufei Ma, and Feng Xu. 4D bioprinting for biomedical applications. *Trends in biotechnology*, 2016, 34.9: 746–756.
- [7] Glowforge, app [online]. 2021 [Accessed 28 May, 2021]. Available from: <https://app.glowforge.com/>
- [8] Chang He, Min Zhang, and Sakamon Devahastin. Investigation on spontaneous shape change of 4D printed starch-based purees from purple sweet potatoes as induced by microwave dehydration. *ACS Applied Materials & Interfaces*, 2020, 12.34: 37896–37905.
- [9] Hopballe, Gaardbutik [online]. 2021 [Accessed 1 June, 2021] Available from: <https://www.hopballe.dk/gaardbutik>
- [10] Jin Huang, Xianju Wang, Qiong Long, Xueyi Wen, Yunjin Zhao, and Liming Li. Influence of pH on the stability characteristics of nanofluids. In: 2009 Symposium on Photonics and Optoelectronics. IEEE, 2009. p. 1–4.
- [11] Instagram, Rene Redzepi Noma [online]. 2021 [Accessed 22 May, 2021]. Available from: <https://www.instagram.com/p/COBFokqHSQx/>
- [12] Rasu Jayabalan, Radomir V. Malbaša, Eva S. Lončar, Jasmina S. Vitas, Muthuswamy Sathishkumar. A review on kombucha tea—microbiology, composition, fermentation, beneficial effects, toxicity, and tea fungus. *Comprehensive Reviews in Food Science and Food Safety*, 2014, 13.4: 538–550.
- [13] Junkfood, blog [online]. 2021 [Accessed 1 June, 2021] Available from: <https://junkfood.dk/blog/>.
- [14] Viirj Kan, Emma Vargo, Noa Machover, Hiroshi Ishii, Serena Pan, Weixuan Chen, and Yasuaki Takehi. 2017. Organic Primitives: Synthesis and Design of pH-Reactive Materials using Molecular I/O for Sensing, Actuation, and Interaction. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17). Association for Computing Machinery, New York, NY, USA, 989–1000.
- [15] Alias Abd Karim. Electrical Double Layer & Zeta Potential. In Emulsion Stability [online]. 2013, slide 10. Available from: <https://www.slideshare.net/akarim717/emulsion-stability>
- [16] Zhenbin Liu, Chang He, Chaofan Guo, Fengying Chen, Bhesh Bhandari, Min Zhang. Dehydration-triggered shape transformation of 4D printed edible gel structure affected by material property and heating mechanism. *Food Hydrocolloids*, 2021, 115: 106608.
- [17] S. H. Lv. High-performance superplasticizer based on chitosan. In: Biopolymers and Biotech Admixtures for Eco-Efficient Construction Materials. Woodhead Publishing, 2016. p. 131–150.
- [18] G.R Mahdavinia, A Pourjavadi, H Hosseinzadeh, M.J Zohuriaan. Modified chitosan 4. Superabsorbent hydrogels from poly (acrylic acid-co-acrylamide) grafted chitosan with salt-and pH-responsiveness properties. *European Polymer Journal*, 2004, 40.7: 1399–1407.
- [19] Harold James McGee. *Nose Dive, A Field Guide to the World's Smells*. Penguin Putnam Inc, October 2020. ISBN-13 : 978-1594203954
- [20] Elodie Melro, Filipe E. Antunes, Gabriela J. da Silva, Inês Cruz, Philippe E. Ramos, Fátima Carvalho and Luís Alves. Chitosan Films in Food Applications. Tuning Film Properties by Changing Acidic Dissolution Conditions. *Polymers*, 2021, 13.1: 1.
- [21] Laia Mogas-soldevila, Jorge Duro-royo, Neri Oxman. Water-based robotic fabrication: large-scale additive manufacturing of functionally graded hydrogel composites via multichamber extrusion. *3D Printing and Additive Manufacturing*, 2014, 1.3: 141–151.
- [22] Mona Lisa, 3D Chocolate [online]. 2021 [Accessed 22 May, 2021]. Available from: <https://www.barry-callebaut.com/en/artisans/mona-lisa/3dstudio>
- [23] Rasmus Munk. 2020. Holistic Cuisine. *ALCHEMIST*. Retrieved January 5, 2021 from <https://alchemist.dk/holistic-cuisine/>
- [24] Mystic Moments, Chitosan Powder [online]. 2019 [Accessed 3 April, 2021]. Available from: [www.mysticmomentsuk.com/products/chitosan-herbal-extracts](http://www.mysticmomentsuk.com/products/chitosan-herbal-extracts)
- [25] Pilar Opazo. 2012. Discourse as driver of innovation in contemporary haute cuisine: The case of elBulli restaurant. In *International Journal of Gastronomy and Food Science*. 1,2, 82–89. DOI: <https://doi.org/10.1016/j.ijgfs.2013.06.001>
- [26] Oxford Vitality, Chitosan Powder [online]. 2020 [Accessed 20 March, 2021]. Available from: <https://oxfordvitality.co.uk/products/chitosan-powder?variant=34728275050662>
- [27] Betina Piqueras-Fizman, Jorge Alcaide, Elena Roura, and Charles Spence. 2012. Is it the plate or is it the food? Assessing the influence of the color (black or white) and shape of the plate on the perception of the food placed on it. In *Food Quality and Preference* 24, 1, 205–208. DOI: <https://doi.org/10.1016/j.foodqual.2011.08.011>.
- [28] Niki Segnit, Douglas Harper, Patrizia Faccioli. *The Flavour Thesaurus: Pairings, Recipes and Ideas for the Creative Cook*
- [29] R. Shepherd, S. Reader, A. Falshaw. Chitosan functional properties. *Glycoconjugate journal*, 1997, 14.4: 535–542.
- [30] Charles Spence. 2017. *Gastrophysics: The new science of eating*. Penguin UK.
- [31] Scott E. Stapleton, Dorit Kaufmann, Helga Krieger, Jan Schenk, Thomas Gries, David Schmelzeisen. 2019. Finite element modeling to predict the steady-state structural behavior of 4D textiles. *Textile Research Journal*. 89,17,3484–3498. DOI: <https://doi.org/10.1177/0040517518811948>
- [32] Nanette Stroebele and John M. De Castro. 2004. Effect of ambience on food intake and food choice. In *Nutrition* 20, 9, 821–838. DOI: <https://doi.org/10.1016/j.nut.2004.05.012>
- [33] Amelia Sydney Gladman, Elisabetta A. Matsumoto, Ralph Nuzzo, Lakshminarayanan Mahadeva, Jennifer A. Lewis.

2019. Biomimetic 4D printing. In *Nature Materials* 15, 413–418 DOI:<https://doi.org/10.1038/nmat4544>

[34] Ye Tao, Youngwook Do, Humphrey Yang, Yi-Chin Lee, Guanyun Wang, Catherine Mondoa, Jianxun Cui, Wen Wang, and Lining Yao. 2019. Morphlour: Personalized Flour-based Morphing Food Induced by Dehydration or Hydration Method. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (UIST '19)*. Association for Computing Machinery, New York, NY, USA, 329–340. DOI:<https://doi.org/10.1145/3332165.3347949>

[35] Upprinting Food [online]. 2021 [Accessed 1 June, 2021]. Available from: <https://www.upprintingfood.com>

[36] Harrar Vanessa, Charles Spence. 2013. The taste of cutlery: how the taste of food is affected by the weight, size, shape, and colour of the cutlery used to eat it. In *Flavour*, 1–13. DOI: <https://doi.org/10.1186/2044-7248-2-21>

[37] Wen Wang, Lining Yao, Teng Zhang, Chin-Yi Cheng, Daniel Levine, and Hiroshi Ishii. 2017. Transformative Appetite: Shape-Changing Food Transforms from 2D to 3D by Water Interaction through Cooking. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. Association for Computing Machinery, New York, NY, USA, 6123–6132. DOI:<https://doi.org/10.1145/3025453.3026019>

[38] 2020. White Guide Nordic 19–20 – Denmark: The epicentre of the New Nordic. White Guide. Retrieved January 5, 2021 from <https://whiteguide.com/nordic/en/news/2283-white-guide-nordic-19-20-denmark-the-epicentre-of-the-new-nordic>

[39] Humphrey Yang, Danli Luo, Kuanren Qian, and Lining Yao. Freeform Fabrication of Fluidic Edible Materials. In: *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 2021. p. 1–10.

[40] Lining Yao, Jifei Ou, Chin-Yi Cheng, Helene Steiner, Wen Wang, Guanyun Wang, and Hiroshi Ishii. 2015. BioLogic: Natto Cells as Nanoactuators for Shape Changing Interfaces. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. Association for Computing Machinery, New York, NY, USA, 1–10. DOI:<https://doi.org/10.1145/2702123.2702611>

[41] Chan Ming Yeng, Husseinsyah Salmah, Sung Ting Sam. Corn cob filled chitosan biocomposite films. In: *Advanced Materials Research*. Trans Tech Publications Ltd, 2013. p. 649–652.

[42] Xiaolin Yu, Buqian Xu, Masayoshi SAWAMURA. Determination of sugar and organic acid contents in yuzu juices from different districts of Japan by HPLC. *Journal of the Japanese Society for Horticultural Science*, 2004, 73.3: 293–298.

## APPENDICES

APPENDIX A: FMP Proposal

APPENDIX B: Experiments

APPENDIX C: Reaction Videos

APPENDIX D: Brainstorm Sessions Chefs

APPENDIX E: Files and Settings Shape Development

Appendix A t/m E can be found in online folders through this link:

<https://drive.google.com/drive/folders/1GiFIR3RHofnh5d2hQGxrczxAffGUMXnB?usp=sharing>

The Demoday with a video and pictures of the project can be found through this link:

<https://demoday.id.tue.nl/projects/A3rjk1oL27>