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Understanding 3D food printing technology: An affordance approach

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ABSTRACT

3D food printing is an emerging technology which has seen increasing interest in its application across different sectors of society. Despite this, there have been limited efforts to examine and understand the technology through social scientific perspectives. This paper bridges this gap by analyzing 3D food printing technology using an affordance approach in order to better understand its unique features and possible use cases. We propose a taxonomy of 3D food printing technology affordances – amalgamation, nutritional customization, textural customization, flavor customization, visual customization, and phygitalization. Drawing on contemporary work on technological affordances (Davis & Chouinard, 2017), we describe how this taxonomy can be applied to draw useful ways of thinking surrounding the development, design, and implementation of 3D food printing technologies across different sectors in society.

1. Introduction

In the popular Japanese anime "Shokugeki no Soma", character Alice Nakiri specializes in using futuristic machines in the kitchen to create food that leaves the audiences in awe. While this remains in a fictitious setting, the methods of food preparation today have now become increasingly complex, and Alice's machinery are closer to reality. 3-dimensional (3D) printing is an emerging technology which has the potential to create customized food with complex shapes, geometries, textures, and nutritional content [1]. 3D printing provides the freedom to design, manufacture, and innovate in various domains, with some researchers suggesting that it contributes to a new industrial revolution [2]. With several possible applications, such as in designing functional foods [2], bio-based products, and even 4D printed food [3], there has been an increasing number of research across disciplines examining the technology and its possibilities [4].

Despite the rapid development of 3D food printing and its potential implications on various aspects of food production, there have been limited efforts to study and understand the technology through social scientific perspectives. To bridge this gap, we utilized the analytical concept of affordances to extend our understanding of the relationship between individuals and 3D food printing technology across contexts. We tap on two models of affordances as articulated by Davis and Chouinard (2016) and Evans et al (2017) to deconstruct 3D food printing technology, which leads to the generation of a taxonomy of affordances which we hope will be useful as a starting point for social scientific researchers to study the technology and its impact, as well as for designers and engineers to consider how future 3D food printers can be designed to shape the way it is used across contexts.

2. What is 3D food printing technology?

3D printing – or additive manufacturing – creates physical objects from geometrical representations through the successive addition of materials [6]. On the other hand, traditional manufacturing involves casting, molding, and machining – also known as subtractive techniques – where objects are created from the subtraction of material from a workpiece [7]. In contrast, additive manufacturing creates objects from the bottom up by adding materials one layer at a time. Developments in additive manufacturing have enabled 3D printed objects to be on par with their traditionally manufactured counterparts, with use cases in different fields ranging from dentistry [8], optics [9], and even healthcare [10].

A decade ago, 3D printing technology was not cost-effective. In recent years, 3D printers have become more reliable and affordable, characterized by cheaper, more user-friendly, and accurate

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3D printers. Coupled with the ease of access of 3D models and the availability of free software, there is a proliferation of 3D printers in the market [4]. These recent advancements in 3D printing have allowed engineers to attempt to print 3D printed food using edible inks.

3D food printing is a novel approach to food production which integrates 3D printing technology to the food manufacturing process, enabling the production of foods with customized shapes, colors, and nutrition, among others [11]. This technology, also known as Food Layered Manufacturing (FLM), utilizes a digital robotic construction process that builds up solid forms comprising edible ingredients layer by layer [12]. Additive manufacturing is progressive, which implies that fine details can be altered along the way until the desired product is achieved. In contrast, our everyday kitchen processes are transformative. We usually combine, heat, and cool our ingredients in the kitchen, introducing chemical reactions until the ingredients transform into new shapes, textures, and flavors [13].

Four techniques of 3D food printing are currently available – extrusion-based printing, inkjet printing, selective sintering printing, and binder jetting [4,14,15]. We briefly discuss extrusion-based and inkjet printing as they are two of the most popular techniques in applying 3D printing to food production.

First, extrusion-based techniques rely on continuous ink flow in a layer-by-layer fashion using high colloidal inks [14]. The melted materials, like chocolate, dough, cheese, and meat paste, are extruded continuously with a moving nozzle and welds to the preceding layers on cooling during the food printing process. This technique can be applied to various soft materials but is limited as it is prone to distortion and warping [15].

Next, inkjet printing deposits liquid droplets onto a substrate guided by computer-assisted design systems and is used to handle low-viscosity materials used in graphical decoration and fillings [14]. There are two main kinds of inkjet printing methods: continuous jet printing and drop-on-demand printing. Continuous jet systems are generally faster but less precise with a lower resolution than drop-on-demand printing. This is due to the low viscosity materials handled by inkjet printers, which by nature do not possess much mechanical strength. As a result, it is usually used to print two-dimensional images [15].

The notion of digital production of food has driven the idea of digital gastronomy [16], which has resulted in several concept designs which have served as inspirations to the possibilities of integrating digital fabrication technology such as 3D printing into food production. For example, the Digital Fabricator is a concept design exploring the convergence of digital 3D printing and food by replacing 3D deposits from the standard 3D printer with food instead, along with a cooking chamber [13]. This fabrication process allows for the creation of flavors and textures that cannot be achieved through other cooking techniques but also allows the user to have control over the minute details of the meal, like the origin and quality of the ingredients [16].

3. Research gap

Existing reviews of 3D food printing technology have focused on examining trends in 3D food printing, the state of 3D food printing technologies, factors associated with the accuracy and quality of print, potential markets, and consumer acceptance [1,2,15,17–19]. In a comprehensive review, Baiano covered the spectrum of topics related to 3D printed foods, from its history and current state of research to consumer attitude and regulatory frameworks [4]. Despite these, existing reviews have largely approached 3D food printing from either an engineering or a food science perspective, with little to no examination of 3D food printing from a social scientific perspective, which may provide unique theoretical insights which can further guide our thinking about the role in which 3D food printing can potentially play in society.

To fill this gap, we used the analytical concept of affordances to deconstruct 3D food printing technology using a model of affordances as articulated by Davis and Chouinard [5]. As with the use of affordances to examine other emerging technology - such as information communication technologies [20] - this can lead to the development of a taxonomy of affordances which serves as a starting point for social scientific researchers to study 3D food printing and its impact on society. As such, this study aims to apply the concept of affordances to examine 3D food printing technologies, centering on the following research questions:

RQ1: How can affordances of 3D food printing technologies be articulated?
RQ2: How can an understanding of these affordances contribute to our understanding of 3D food printing technologies and its possible applications in society?

4. A taxonomy of 3D food printing technology affordances

The concept of affordance has become a popular analytical approach to study emerging technology across disciplines as wide-ranging as psychology, science and technology studies, design, communication, education, and human–computer interaction [5,20–23]. Broadly, the term *affordance* refers to the range of action possibilities and constraints a sociotechnical system available to a subject. In the context of this paper, the sociotechnical system relates to 3D food printers.

The term has been widely used across multiple disciplines, with has led to a multiplicity of meanings attached to it. Affordances were first described in ecological psychology to refer to actionable properties of the environment which offers an animal some sort of action possibility [24,25]. Some years later, Norman proposed another definition for the concept by referring to affordances as specific properties of objects which determine how said objects could be used, bringing the concept relevant to design studies [26]. For example, a chair is designed in such a way which provides support for when a human is sitting, and hence, affords sitting. He further described the difference between real and perceived affordances, with real affordances referring to the potential use cases of a particular objects and perceived affordances referring to features of use which are clear to the user [27].

Across the two decades or so since Norman's proposed definition, the concept of affordance has occasionally been employed in poorly defined ways across disciplines, with some suggesting that the concept is too ambiguous to be analytically useful [28]. Despite this, recent theoretical work on affordances have sought to clarify the concept and provide frameworks in which to deconstruct and study sociotechnical systems through the such a conceptual lens.

For example, Evans and colleagues conceptualize affordances as the intricate relational structure "between an object or technology and the use which enables or constrains potential behavioral outcomes in a particular context (p. 36) [21]". They went further to provide scholars with three criteria to determine what makes an affordance – it must be *variable*, *not a feature* of the technology, and is *not an outcome*. Likewise, Davis and Chouinard provides a clearly defined theoretical framework in which to situate analyses of technological objects, highlighting the mechanisms and conditions in which affordances afford certain outcomes of use within certain contexts [5]. Specifically, affordances reflect the way in which objects *request*, *demand*, *allow*, *encourage*, and/or *refuse* actions. Furthermore, these mechanisms are conditional upon certain conditions, namely *perception* (or users' awareness of functions), *dexterity* (or skill and ability of the user), and *cultural and institutional legitimacy* (or social support in executing the function).

Building on these theoretical foundations, we utilize the analytical lenses of affordances to examine 3D food printing technology. Through an extensive literature review and analysis, we distilled a taxonomy of 3D food printing technological affordances comprising of six distinct affordances – amalgamation, nutritional customization, textural customization, flavor customization, visual customization, and phygitalization.

Amalgamation refers to the possibility of combining two or more properties to form a new entity. Here, we refer to the amalgamation process of 3D food printing as mixing different ingredients to create something unique. The rheological characteristics of 3D food printing materials – or ink – are requirements for estimating and improving the printing performance [29]. Hence, materials are usually added to achieve the required rheological properties such that they can be printed. In the different printing techniques, different materials should be used depending on the machine requirements. For example, inkjet printers require more viscous materials to be added. Xanthan gum is a commonly used thickening agent added to different ingredients to allow food to be printed [30]. This suggests that amalgamation is a key affordance of 3D food printing technology.

Because of amalgamation, the possibility of using a combination of multiple new materials to be printed is substantial. In the Digital Fabricator, the proposed idea of mixing and matching different content is an example of amalgamation as an affordance [13]. Here, we can see the role of a 3D food printer as combining different ingredients to form a new product and replacing materials that are already present with something else.

Nutritional customization refers to the affordance which enables 3D food printers to specify the exact nutritional properties of food products a user wants to create. For example, Severini and colleagues reported that they were able to create cookies using 3D printing which had 15 % of fat replaced with inulin, a non-digestible oligosaccharide which has beneficial properties such as healthy gut bacteria growth, calorie and fat reduction, and calcium absorption, among others [31]. This illustrates how a 3D printer could afford the creation of foods with specific nutritional content.

Visual customization refers to the ability for 3D printers to alter the appearance of food, such as texture, shape, and color and manipulate perceptions. Although the purpose of food is fundamentally nutritional, the visual perception of food is as important as the taste itself. For example, Hutchings asserts that the importance of customizing the visual appearance of food stems from the human psychological perception of food and the relationship between its appearances and taste [32].

While evaluating food, the expectation of liking it plays an important role, and there is increasing evidence that the consumers' expectation of the product can enhance or degrade the perception of it before it is even tasted [33]. 3D food printing can afford visual customization of food products as they are printed layer by layer, thus allowing for greater accuracy in the food's visual outcome. In traditional food preparation methods, the aesthetic value of food may lead to a compromise in food quality [34]. With 3D food printing technology, we can customize the visual appearance of a food product to ensure that it is aesthetically pleasing to the consumer without decreasing the overall quality of the product. One in-depth study revealed that specific inputs of 3D food printing could be altered to customize the visual appearance of food products, such as anthocyanin-PS gels. By altering the amount of anthocyanin-PS gels used and its concentration, the experiment produced yoghurt of different colors and transparency levels while ensuring that the overall nutritional content remained constant [35]. The experiment also showed that consumers were more inclined to consume the more aesthetically pleasing yoghurt, even though they all had the same taste. Therefore, 3D food printing can afford the visual customization of food products to a desired level of aesthetics**.**

Textural customization goes beyond nutritional customization and describes how 3D food printers can offer users ways in which the textural qualities of food can be manipulated. An example is the printing of cultured meat using bioinks [36]. Bioinks consist of cells and biomaterials and is an essential aspect of the printing process as it fabricates the scaffolding structures where muscle fibres are formed to become meat eventually [37]. Here, 3D food printing allows cells and biomaterials to be printed in a particular architecture to specify the exact textural qualities of a food product. In the traditional method of culturing meat, the meat is produced by proliferating cells, and 3D food printing is thus advantageous as it can produce meat with better texture.

Flavor customization refers to 3D food printing technology's affordance in allowing food producers create different flavor profiles of products through the merging of different ingredients [38]. In traditional cooking, we create the flavor we want by adding spices and different ingredients. In the same way, 3D food printing allows us to specify properties that we want to achieve by allowing the user to selecting specific ingredients and inks, or in changing printer settings.

Phygitalization refers to the possibility for 3D food printing to connect the digital and physical world. This affordance is characterized by the transformation from a digital space to a physical product. We can understand this from how a 3D printer works – the design of a printable object is first built on computer aided design (CAD) systems where a 3D virtual model is first planned. It is then converted to information which controls the movements of the printers which eventually prints the food [14].

Currently, technologies like the Thermomix, which is a blender that helps to cook and stir food at an adjustable temperature, also exhibit phygitalization as an affordance. The Thermomix comes pre-loaded with recipes so it can instruct, step-by-step, how to make the dish you want (DiGregorio, 2017). The appeal of the Thermomix is that you can cook without expending significant cognitive resources – there is no need to monitor the progress of the food as you go along. Like the Thermomix, 3D food printers can have recipes - or in this case, CAD models - uploaded on to them, which will then aid in the cooking process by printing the food. This process also manifests by augmenting users' experience of a physical activity with a digital extension. Started in 2006, the Fab@Home project aimed to put solid freeform fabrication technology into the hands of inventive and entrepreneurial individuals and was the first multi-material 3D printer available to the public and one of the first two open-sourced DIY 3D printers [39]. The success of this project was largely social, where the community shared designs online and made it easy for everybody to access and print their own designs. In the same way, 3D food printers afford such communication through digitization by encouraging participation in these communities that were built for 3D printing technology.

Many products have been transformed digitally in the recent few years, from books to entertainment and even how we learn. Looking at eBooks, the digitizing of books now bring convenience to the reading process by allowing users to download books and to save space by reducing the need to physically keep books [40]. It also helps to overcome disabilities in reading for older people with eyesight problems and medical issues by changing font sizes for maximum legibility. Similarly, 3D food printers can bring convenience by allowing users to download recipes. It allows users to overcome disabilities by reducing the barrier to entry for cooking and making our food and keeps the cooking process simple for all. In the digital age, it is possible for users to precisely control the nutritional value, quality, flavors, and texture in each meal through a touch-screen interface and internet connectivity [41]. Furthermore, as the food printer can be connected to the Internet, the food printer could order new ingredients when required. CAD, scanners, and other software that are freely available on the Internet also allow people to touch and feel the designs.

One other outcome arising from phygitalization is increased creativity and innovation in food design. Olsen asserts that design thinking can contribute to the food industry, and one aspect of design thinking is rapid prototyping, which aims to use a model or sketch to express ideas [42]. In the design process for 3D printed foods, CAD designs are pivotal to the process as they form the basis of what is to be printed. As we can now work on and move from CAD models before creating the food, it would enable users to go beyond habits and legacy equipment in cooking that could constraint creativity.

5. Applying the taxonomy

In accordance with Evans et al [21], amalgamation, nutritional customization, textural customization, flavor customization, visual customization, and phygitalization are *variable* (e.g., specific 3D food printing solutions can vary in their ability to allow for different ingredients to be combined), are *not features* (e.g., specific features such as internet connectivity enable recipe sharing through digitization), and are *not outcomes* (e.g., nutritional customization affords the creation of healthy 3D printed foods, which is the outcome).

Viewing from the conceptual lens developed by Davis and Chouinard, we can also explore how these affordances may activate outcomes through different mechanisms dependent on the conditions of the affordance [5]. For example, the abovementioned affordances may *encourage* or even *demand* the adoption and sharing of 3D food printing as a viable, or even desirable, mode of food production among those who have awareness of it as a tool for precise and highly customizable food production (*perception*), have the digital skills necessary to deploy features tapping on the various affordances (*dexterity*), and have the necessary societal support such as regulations surrounding 3D printed foods (*cultural and institutional legitimacy*).

The taxonomy we proposed, in relation to the affordance framework by Davis and Chouinard (2016), can be used in several ways. First, the taxonomy can help inform engineers, designers, and policymakers working with 3D food printing technologies to better achieve various goals. For example, 3D food printing systems may be applied in the healthcare setting to provide nutritious and appealing meals for dysphagic patients [43,44]. If users were to be nurses or hospital staff operating the 3D food printing system, then it is necessary for designers of such systems to consider the extent of the system in which the various affordances are to be manifested in specific features. Should we maximize the ability to customize the nutritional and textural properties of the food, but limit phygitalization in the system, to ensure the delivery of personalized nutrition to patients without overburdening hospital staff in terms of learning and training in using the system? Furthermore, as explicated by Davis and Chouinard (2016), dexterity and cultural and institutional legitimacy is a necessary condition in which the affordance can work in positive or negative ways. In developing such a system, it is necessary for designers or hospital administrators to ensure sufficient training and institutional support is provided. Otherwise, affordances such as nutritional customization may merely *allow* rather than *encourage* the use of the system to feed hospital patients.

Second, the taxonomy allows stakeholders to better understand the costs and benefits of different technologies in 3D food printing. The extent in which the affordances described can be tapped on will directly affect the cost of developing or integrating a 3D food printing system in a particular context. For example, if food producers would like to explore the use of 3D food printing to pursue sustainability goals through the consumption of alternative and less desired food sources such as insect protein, the affordances of visual, textural, and flavor customization makes it highly attractive as a solution to de- and reconstruct food sources. It also provides a useful way to compare across tools in which 3D food printing may face challenges against in terms of adoption. Amalgamation, nutritional customization, textural customization, flavor customization, visual customization, and phygitalization are affordances in which other food production tools also may embody. For example, traditional cooking uses a variety of tools – from knives and mixing bowls to piping bags and molds – to achieve some level of amalgamation, nutritional customization, textural customization, flavor customization, and visual customization. Considering the varied differences of these affordances between traditional or competing tools will allow researchers, policymakers, consumers, and food manufacturers better weigh the costs and benefits of choosing to purchase and use 3D food printing solutions.

Finally, the taxonomy provides a basis for further critique and discussion of the role in which 3D food printing technologies can play across different sectors in society – from healthcare to food product manufacturing. It provides a starting point for discussion and refinement of the study of 3D food printing technologies from an affordance perspective. For example, are there other affordances? Does articulating their affordances make the benefits and drawbacks of different 3D food printing solutions more apparent? Are there ways in which these affordances interact with each other in ways that would potentially drive unique outcomes?

CRediT authorship contribution statement

Kenji C.L. Ling: Conceptualization, writing - original draft, formal analysis, project administration, methodology **Andrew Z.H. Yee:** Conceptualization, writing - original draft and review/editing, formal analysis, supervision. **Chen Huei Leo:** Conceptualization, supervision, resources, project administration. **Chee Kai Chua:** Conceptualization, supervision, resources, project administration

6. Conclusion

In this paper, we proposed a taxonomy which provides an explicit articulation of the affordances of 3D food printing technology. We further highlighted how taking an affordance perspective can guide stakeholders such as engineers, researchers, designers, and policymakers to make more informed choices in the design, development, research, and implementation of 3D food printing technology. It is our hope that this serves as a starting point for more enriching conversations surrounding the development and use of 3D food printing technology in society.

Data availability

No data was used for the research described in the article.

Declaration of Competing Interest

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