Analysis of the Application and Exploration of 3D Printing Technology Used in the Future Takeaway Packaging

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Abstract. Takeaway packaging consumption and demand have skyrocketed in recent years in tandem with the growth of the takeaway industry. Yet, the shortcomings of the commonplace plastic takeaway containers are becoming more noticeable by the day. Sustainability has emerged as a major theme for the future of takeout packaging. Simultaneously, 3D printing technology is quickly advancing and has been widely adopted by the mold-making and packaging industries.

This study proposes two distinct concepts for integrating 3D printing technology to the production process of future takeaway packaging, and refines the lifespan process of the concept takeaway packaging, based on survey results. In addition, the conceptual design of this project included a revolutionary future takeaway box as a product carrier. This study contributes to the sustainable development of the future takeaway packaging sector by applying the concept of sustainable development to the application of 3D printing technology in the design and manufacture of takeaway packaging.

Keywords: 3D printing · takeaway packaging of the future · takeaway box design · sustainable design · biodegradable materials

1 Introduction

During COVID-19, blockade and segregation rules had a huge impact on the offline food service business around the world, causing a chain reaction that drove the expansion of the takeaway market [1]. According to statistics, the online meal delivery industry in Europe is projected to reach $20.27 billion by 2026, expanding at a CAGR of 5.83% between 2020 and 2026. Simultaneously, the rapid expansion of the takeout market has contributed to the increase in consumption and demand for takeout packaging.

Takeaway packaging is a type of food packaging consisting of disposable takeaway boxes and cutlery, bags and beverage bottles. Traditional thermoplastics, like polypropylene (PP) or polystyrene, are used to manufacture the vast majority of plastic takeaway containers currently available on the market (PS). These plastics are derived from nonrenewable petroleum and are not biodegradable [3]. Although these plastics are recyclable in theory, when used as takeout containers, the recycling rate is often very low due to

L. F. Ying et al. (Eds.): ICELA 2022, ASSEHR 730, pp. 916–926, 2023.
https://doi.org/10.2991/978-2-38476-004-6_111

food residues and sauces, and they are disposed of in landfills or incinerated, which has a significant negative impact on the circular economy and the ecological environment [3]. Regarding the manufacturing process, these plastic takeout containers are manufactured by employees pumping raw materials into moulds that are then hot-pressed by CNC machines. However, these massive assembly line machines generate daily carbon emissions that are enormous. On the other hand, because the moulds used to mass-produce the boxes are fixed and it is impossible to make injection moulds with complicated designs, the present common plastic takeaway boxes are unable to match the increasingly individualised wants of consumers [3]. Therefore, sustainability and personalised design have become some of the most crucial features of packaging design systems of the future.

Using 3D printing technology, a computer model is converted directly into a physical object by adding bondable raw materials [5]. This eliminates the need for plastic packaging factories to open or adjust moulds, which not only simplifies the production process but also saves resource waste, and digital design makes it easier for manufacturers to update or develop packaging styles in response to consumer demands [5]. In addition, a variety of biodegradable and sustainable materials are now available for use in 3D printing technologies [6]. In terms of production methods and material applications, 3D printing technology is thus well-suited to the future trend of sustainable takeout packaging.

This study will investigate the advantages of 3D printing technology in mould production based on the current status and issues of plastic takeout containers, as well as existing instances of 3D printing for mass production and applicable sustainable materials. To refine the design of takeout boxes, a questionnaire will be used to collect the opinions and requirements of users regarding takeout packaging. Lastly, with a sustainable design mindset, a conceptual design for using 3D printing to change the future production of takeaway packaging is proposed, and an innovative future takeaway box is designed as a key product to ameliorate the current problems of plastic takeaway boxes and promote the sustainable development of takeaway packaging.

2 Literature Review

2.1 Advantages of 3D Printed Manufacturing Moulds

Currently, injection moulds for takeout containers are manufactured by a CNC milling machine. In contrast to 3D printing technology, this conventional form of mould creation is labor-intensive, expensive, and time-consuming, and it is incapable of producing moulds with complicated geometries due to the injection moulding process [7]. In comparison to conventional procedures, 3D-printed moulds can be more cost-effective. By removing the process of creating and certifying the process from mould design to 3D printing, not only is the manufacturing cycle greatly shortened, but the batches and forms of the moulds may be modified in response to market demand and feedback [7]. And with the benefits of additive manufacturing, 3D printers can not only cut resource consumption and waste, but also print structures with greater complexity. In contrast, with the advancement of 3D printing and ancillary technologies, producers can now

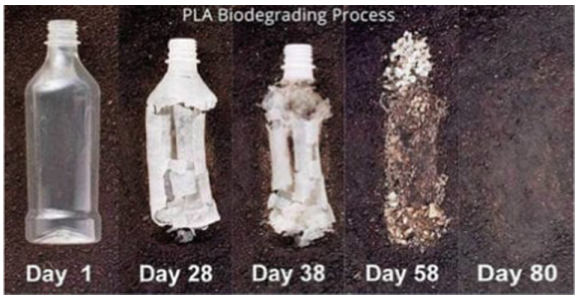

Fig. 1. PLA biodegrading process (Source from the Google)

more precisely manage aspects such as 3D printing time, forming quality, and forming precision [8].

2.2 Application of Sustainable Materials

Traditional plastic takeaway containers are less suitable for the future of takeout packaging than sustainable materials. It is possible to develop sustainable materials without consuming nonrenewable resources and without disturbing the equilibrium of the environment and ecosystem [6]. There are currently a range of sustainable materials for takeaway packaging on the market. One of the most prominent examples is the sugarcane bagasse-dominated paper takeaway container. The sugar cane stems are removed and pulped during the refining process. After being filtered and injected into a mould, they are formed by hot pressing into a container that is both robust and safe. The container can be used for industrial composting as it is biodegradable [11].

However, unlike polylactic acid (PLA), this material is not suitable for 3D printing since it is less rigid and translucent. Polylactic acid (PLA) is a plant-based plastic created from lactic acid polymerized by fermentation of starch and is suitable for 3D printing [12] because of its good thermoplastic and ductile qualities. The 3D printing of PLA materials takes less energy and releases fewer greenhouse gases compared to petroleum-based products. The melting point of PLA is between 150 and 160 °C, and the printing temperature for PLA is between 180 and 230 °C [2]. And PLA is non-toxic and non-hazardous, and its waste can be completely degraded in the specific conditions of industrial composting, i.e. controlled temperature and humidity in the presence of microorganisms (e.g. bacteria, fungi, etc.), converted to carbon dioxide, water, and biomass within months or even days, and the resulting fertiliser can promote plant growth [13]. Although PLA composting creates carbon dioxide, the impact is significantly less than the carbon dioxide and hazardous gases created by conventional plastics during combustion (Fig. 1).

3 Methodology

3.1 Data Collection

The subject of this study was a survey on users' perceptions and needs for takeaway packaging, using a closed online questionnaire format, targeting takeaway users from

all regions. A total of 205 valid questionnaires were collected, of which 47% were male and 53% were female.

This study is a non-scale questionnaire, so there are only two options for the questions, 'yes' or 'no'. The questionnaire contains a total of 24 multiple-choice questions. The first two questions are sample questions, while the other 22 questions are based on the current state of takeaway packaging and user pain points, as well as the potential impact and benefits of 3D printing technology on takeaway packaging.

The questions cover four main dimensions: 3–8 are about users' perceptions of current takeaway packaging and how it is handled, 9–15 are about users' perceptions of takeaway packaging materials, 16–18 are about the impact of information on takeaway packaging on users, and 19–24 are about takeaway packaging design and personalisation needs.

3.2 Data Analysis

The data were analysed using SPSS. In the frequency analysis table below, option 1.0 represents "yes" and option 2.0 represents "no." The data for the first dimension, questions 3 through 8, were examined first. The highest proportion of the sample for question 4 in the table below was "2.0" at 50.73 percent. 83.34% of the sample responded "1.0" to Question 6. Over 70% of the sample were "2.0" in question 7. And at question 8, 66.34 percent of the sample responded "2.0." The examination of the data from these three items in the table indicates that the majority of respondents would discard takeout packaging after consuming their meals (Table 1).

The table below displays the data analysis for the second dimension, questions 9 through 15. The analysis of data from questions 13, 14, and 15 revealed that nearly all respondents disposed of leftover takeout immediately with the box, and the majority were willing to pay more for biodegradable takeout packaging. This demonstrates that sustainable materials must be incorporated into future takeout container designs (Table 2).

The table below displays the data analysis for the third dimension, questions 16 through 18. The table below demonstrates that 61.95% of the sample selected "1.0" for question 16. Over sixty percent of the sample agreed with the response to question 17. There were 63.90 percent "1.0" responses in the sample for question 18. According to the examination of the data from these three questions, the majority of participants can be influenced by the information on the takeout package. This indicates that the design of takeout packaging can be utilised to influence consumers by incorporating brand culture or environmental conservation messages (Table 3).

The fourth dimension is the study of the data for questions 19 through 24. As seen in the table below, more than 70 percent of the sample for question 19 was "1.0." The question 20 received the highest percentage of "1.0" responses (54.63%). Moreover, six percent of the sample for question 22 was "1.0." The majority of participants preferred an all-in-one takeaway box and were willing to accept customizable sizes, which could be an important design opportunity for this study. Approximately 83.41% of the sample responded "1.0" to question 21, which had the highest percentage. 81.9% of the sample responded "1.0" to Question 23. 83.90% of the sample population responded "1.0" to Question 24. According to the analysis of data from questions 21, 23, and 24,

Table 1. Frequency analysis 1 (Made by author)

Frequency analysis results				
Name	Options	Frequency	Percent (%)	Cumulative percentage (%)
3 Do you often use your mobile phone to order food on the food delivery app?	1.0	183	89.27	89.27
	2.0	22	10.73	100.00
4 When you order takeout, do you ask for cutlery?	1.0	101	49.27	49.27
	2.0	104	50.73	100.00
5 Do you feel that the current takeaway is over-packaged?	1.0	123	60.00	60.00
	2.0	82	40.00	100.00
6 Do you throw away all takeout boxes after eating?	1.0	171	83.41	83.41
	2.0	34	16.59	100.00
7 Do you wash and leave some good quality takeaway boxes?	1.0	54	26.34	26.34
	2.0	151	73.66	100.00
8 Are you going to reuse these takeout boxes after eating out?	1.0	69	33.66	33.66
	2.0	136	66.34	100.00
Total		205	100.0	100.0

Table 2. Frequency analysis 2 (Made by author)

Frequency analysis results				
Name	Options	Frequency	Percent (%)	Cumulative percentage (%)
9 Do you care about the material of takeaway packaging?	1.0	93	45.37	45.37
	2.0	112	54.63	100.00
10 Do most of your takeaway orders come in plastic boxes?	1.0	170	82.93	82.93
	2.0	35	17.07	100.00
11 Do you understand the current waste and pollution of takeaway packaging?	1.0	109	53.17	53.17
	2.0	96	46.83	100.00

(*continued*)

Table 2. (*continued*)

Frequency analysis results				
Name	Options	Frequency	Percent (%)	Cumulative percentage (%)
12 Did you know that most plastic boxes are made of petroleum and pollute the environment?	1.0	89	43.41	43.41
	2.0	116	56.59	100.00
13 Will you throw away the unfinished takeout without sorting the garbage, and throw it away directly with the takeaway box?	1.0	185	90.24	90.24
	2.0	20	9.76	100.00
14 Biodegradable packaging can be thrown away with food scraps, will you accept it?	1.0	195	95.12	95.12
	2.0	10	4.88	100.00
15 Are you willing to pay a little more for compostable packaging when ordering takeout?	1.0	163	79.51	79.51
	2.0	42	20.49	100.00
Total		205	100.0	100.0

Table 3. Frequency Analysis 3 (Made by author)

Frequency analysis results				
Name	Options	Frequency	Percent (%)	Cumulative percentage (%)
16 Do you notice the information on the takeout packaging when you eat takeout?	1.0	127	61.95	61.95
	2.0	78	38.05	100.00
17 Can the brand message on the takeaway box promote your understanding of the brand culture?	1.0	132	64.39	64.39
	2.0	73	35.61	100.00
18 Does the eco-friendly slogan on the packaging make you aware and encourage you to recycle takeaway packaging?	1.0	131	63.90	63.90
	2.0	74	36.10	100.00
Total		205	100.0	100.0

Table 4. Frequency analysis 4 (Made by author)

Frequency analysis results				
Name	Options	Frequency	Percent (%)	Cumulative percentage (%)
19 Do you accept the integrated design of cutlery and packaging?	1.0	149	72.68	72.68
	2.0	56	27.32	100.00
20 Do you think the size of a regular takeaway box is right for you?	1.0	112	54.63	54.63
	2.0	93	45.37	100.00
21 Would you like your takeaway box to be customizable?	1.0	171	83.41	83.41
	2.0	34	16.59	100.00
22 If the size of the box can be customized, would you be willing to accept a takeaway box that fits your appetite?	1.0	138	67.32	67.32
	2.0	67	32.68	100.00
23 If possible, would you like to personalize the box (shape and colour)?	1.0	168	81.95	81.95
	2.0	37	18.05	100.00
24 Compared with ordinary clear or white packaging boxes, do you prefer more attractive and designed boxes?	1.0	172	83.90	83.90
	2.0	33	16.10	100.00
Total		205	100.0	100.0

the vast majority of respondents disliked the standard takeaway packing and desired customization (Table 4).

4 Result

4.1 Concept Design 1

The first concept design employs 3D printing technology in place of conventional mold-making techniques for the production of plastic takeout containers. Once the takeaway box shape design has been selected in the early stages of production, the designer creates a CAD model of the takeout box mould using electronic equipment. The appropriate digital model and metal materials for the mould are then imported into an industrial 3D printer, and the mould is manufactured using metal additive manufacturing (MAM) [14]. Finally, the finished moulds are loaded onto a hot press forming assembly line machine and put into production for takeaway packing.

The primary material utilised in the bulk manufacture of takeout containers is bagasse from sugarcane pulp. The bagasse is pulped and filtered before being transferred to the manufacturing facility. Starting the mass manufacture of takeaway boxes, a machine on an assembly line injects pulpy bagasse into a thermoplastic mould [4]. When the

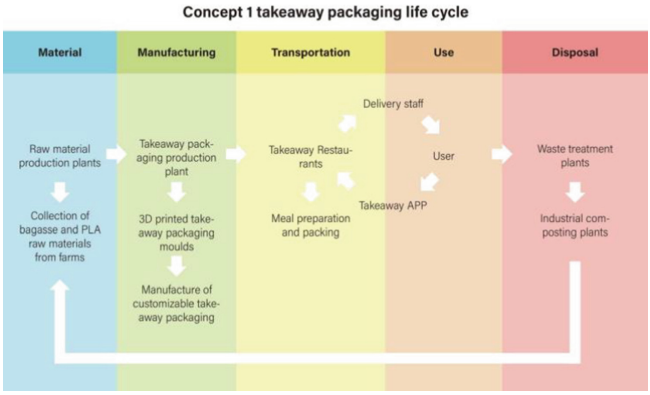

Fig. 2. Concept 1 - takeaway packaging life cycle process (drafted by author)

takeaway box must be customised or enhanced, the mold's digital model must be changed and the production process must be repeated.

At the usage and disposal stage of the takeaway box, there is no need to clean up any leftover food or sauces, and the box may be placed immediately in the compost bin. The material is then taken to an industrial composting facility where it is composted and biodegraded professionally.

The fully decomposed biofertiliser is then sent to fields, where it is utilised to cultivate crops and raw materials for the boxes (Fig. 2).

4.2 Concept Design 2

The design concept for the second notion is to leverage 3D printing technology to totally replace conventional assembly lines and directly create takeout boxes in bulk. With these advantages of 3D printers, takeout boxes may be customised and manufactured immediately in the takeout store.

First, the raw PLA material is sent to the production factory or directly to the takeout store. Next, the designer produces a digital model of the takeaway box based on the brand's specifications or the user's requirements. Simultaneously, the user can personalise the box using the takeout app on their mobile device. The digital model is then loaded onto an industrial 3D printer to begin producing in large quantities. Lastly, the takeaway boxes produced in the manufacturing plant are transported to the takeaway shop for use [9], whereas the takeaway boxes produced in the takeaway shop do not need to be transported, thereby not contributing to the carbon footprint, and can be used directly in the shop for packing the takeaway.

Concept 2 disposes of the takeaway container similarly to Concept 1 throughout the usage and disposal phase. The user can dispose of the PLA takeaway container along with food waste in a biodegradable container. The PLA takeaway container is then transported with the same sort of waste to an industrial composting facility, where it is composted and biodegraded professionally. The fully decomposed bio fertiliser is then sent to farms where it is utilised to cultivate crops and raw materials for packaging (Fig. 3).

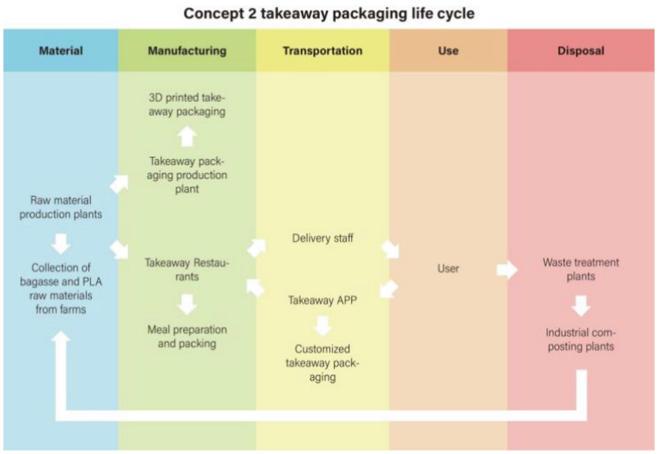

Fig. 3. Concept 2 - takeaway packaging life cycle process (drafted by author)

Fig. 4. Key product design model (Photo Credit: Original)

4.3 Key Product Design

This design merges the cutlery with the takeout container. The silverware is attached to the lid via a tiny connection, and both the box and the cutlery are composed of PLA, which is physically stronger. Using a little strain, the cutlery can be separated from its connection to the lid and used. On both sides of the lid are little clips that can be used to secure a napkin over the cutlery to protect its cleanliness [10].

There are numerous alternatives and combinations of cutlery to accommodate various food types and cultures, hence meeting the requirements of users from various regions. The length of the cutlery is shorter than the length of the box, allowing the user to dispose of the silverware more efficiently.

Users can customise the colour and size of the box to their specifications, as well as the lid and bottom of the interior box. These placements are imprinted by default with an environmental motto or brand cultural message. Both the stylistic design of the

integrated tableware and the aforementioned customizable functional design are based on the design concept II suggested in this study (Fig. 4).

5 Conclusion

This design combines the cutlery and takeout container. Both the box and the cutlery are made of PLA, which is physically stronger. The silverware is fastened to the lid by a microscopic connection. The cutlery may be detached from its connection to the lid and used with minimal effort. On both sides of the lid are small clips that can be used to secure a napkin over the silverware so that it remains clean.

There are several variations and combinations of cutlery to fit varied food types and cultures, hence addressing the needs of consumers from a variety of geographic regions. The length of the cutlery is shorter than the length of the box, allowing for more effective disposal.

The colour and size of the box, as well as the lid and bottom of the internal box, are customizable by the user. By default, these placements are imprinted with an environmental slogan or a brand's cultural statement. Both the aesthetic design of the integrated tableware and the previously mentioned customisable functional design are based on the design concept II proposed in this study (Fig. 5).

References

1. Zhang Xin and Wang Jia, 'Research on takeaway food packaging design in the post-epidemic era', China Packaging, vol. 42, no. 06, pp. 26-29, 2022.
2. Liu Shuo, Guo Kaiwen, Xiang Hubing, and Zhu Denghua, 'Research on recycling and improvement of take-away packaging in China', Leather Making and Environmental Technology, vol. 2, no. 07, pp. 159-160, 2021.
3. Song Han, 'Existing problems of takeaway food packaging and related countermeasures analysis', Industrial Design, no. 12, pp. 75-76, 2018.
4. Chen Wei, 'Food takeaway packaging design based on the design concept of "humanability"', Packaging Engineering, vol. 40, no. 20, pp. 63–66+80, 2019, doi: https://doi.org/10.19554/j.cnki.1001-3563.2019.20.010.
5. Meng Wei, 'Analysis of 3D printing technology and application trends', Science and Technology Innovation and Applications, no. 11, pp. 146-148, 2021.
6. Deng, Pingyao, 'Analysis of the impact of 3D printing technology on mould manufacturing technology', Wireless Connected Technology, vol. 15, no. 18, pp. 138–139+142, 2018.
7. Chen Fang, 'Exploring the application of 3D printing technology in mould manufacturing', Chinese and Foreign Entrepreneurs, no. 27, p. 110, 2019.
8. H. Zeidler, D. Klemm, F. Böttger-Hiller, S. Fritsch, M. J. Le Guen, and S. Singamneni, '3D printing of biodegradable parts using renewable biobased materials', Procedia Manufacturing, vol. 21, pp. 117–124, Jan. 2018, doi: https://doi.org/10.1016/j.promfg.2018.02.101.
9. '3D printing on the road to mass production', Shanghai Building Materials, no. 04, p. 36, 2019.
10. 'Adidas 3D printed shoes to go on sale in March with 100,000 more pairs', Sino-Foreign Footwear, no. 02, p. 96, 2018.
11. Y. R. Loh, D. Sujan, M. E. Rahman, and C. A. Das, 'Sugarcane bagasse—The future composite material: A literature review', Resources, Conservation and Recycling, vol. 75, pp. 14–22, Jun. 2013, doi: https://doi.org/10.1016/j.resconrec.2013.03.002.

12. E. H. Tümer and H. Y. Erbil, 'Extrusion-Based 3D Printing Applications of PLA Composites: A Review', Coatings, vol. 11, no. 4, Art. no. 4, Apr. 2021, doi: https://doi.org/10.3390/coatings11040390.
13. M. Musioł, W. Sikorska, G. Adamus, H. Janeczek, M. Kowalczuk, and J. Rydz, '(Bio)degradable polymers as a potential material for food packaging: studies on the (bio)degradation process of PLA/(R, S)-PHB rigid foils under industrial composting conditions', Eur Food Res Technol, vol. 242, no. 6, pp. 815–823, Jun. 2016, doi: https://doi.org/10.1007/s00217-015-2611-y
14. F. I. Azam, A. M. A. Rani, K. Altaf, T. V. V. L. N. Rao, and H. A. Zaharin, 'An In-Depth Review on Direct Additive Manufacturing of Metals', IOP Conf. Ser.: Mater. Sci. Eng., vol. 328, p. 012005, 2018, doi: https://doi.org/10.1088/1757-899X/328/1/012005.