Zero-waste Food Deliveries and Takeaways: Sustainable Design Solutions through Systems Thinking

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ABSTRACT

The food delivery and takeaway sector generates significant food and packaging waste, posing environmental challenges. In response, this paper presents the process and outcomes of an educational design project that guided students to develop sustainable design solutions for zero-waste food deliveries and takeaways. The project involved 85 students who worked in teams to design a service system and a product family using a systems thinking approach to address the complex network of stakeholders, value propositions, and material flows involved in these services. The paper describes the project stages, the tools and methods adopted for systems thinking, and the pedagogical outcomes regarding design processes and proposals. The paper discusses the implications of the project for reimagining the food delivery and takeaway sector in ways that promote sustainable food practices, support local resources and know-how, and achieve zero food and packaging waste. The paper also reflects on the role of systems thinking in elevating design students' capabilities to deal with complexities inherent in multi-stakeholder problem spaces.

Keywords: systems thinking, sustainable design solutions, business model canvas, food experience, zero waste, educational design project

Introduction

Single-use disposable food and beverage products have become a great environmental problem due to influencing factors such as convenience and hygiene. This was heightened as part of the COVID-19 measures (Molloy et al., 2022), but it persisted even after the restrictions were lifted. When businesses such as canteens, cafeterias, and small restaurants use excessive packaging for takeout and delivery, it contributes to the growing problem of plastic waste (Kochanska et al., 2021), including items such as plastic containers, cutlery, stretch films, and bags. Over-consumption is compounded by

the additional problem of excessive food waste due to poor portioning practices and over-ordering tendencies that arise from increased use of delivery and takeaway services (Trivedi et al., 2023). Through a systems thinking approach, design solutions can be generated that invite a rethink in business and consumer practices, push for more sustainable alternatives, and help designers make better-informed decisions about the entire cycle of the takeaway food experience, including preparation, storing, packaging/transporting, and serving. This constitutes a rewarding challenge for future designers who can foster skills and capabilities in design for sustainability to explore and address intervention areas within complex systems. Hence, we incorporated system thinking into a 14-week-long design project carried out with 85 students at the Department of Industrial Design, Middle East Technical University, Turkey. The project involved conceiving and developing sustainable design solutions in the form of a product family targeted at re-imagining the entire cycle of the takeaway/delivery food experience for healthy and responsible eating and consumption.

Background

Systems of food delivery and takeaway: opportunities and challenges

The food delivery and takeaway services sector has been built around the use of various single-use packaging to ensure that foods reach their destination without getting messed up, without becoming cool (in the case of warm food), and in a form that can be easily handled from kitchen to table. These demands have led to the use of very common single-use material-container combinations, such as cardboard boxes, expanded polystyrene plates, aluminium foil trays, polystyrene cutlery and drink cups. The sector experienced substantial growth during the COVID-19 pandemic, with changing consumer behaviours and expectations and numerous cafes and restaurants switching to this business model simply for survival and new delivery-focused businesses entering the sector (Jia et al., 2022). This was accompanied by advancements in online ordering technology and third-party platforms offering secure transactions, customer support, and courier delivery services. These developments have transformed the sector in line with increased interest in convenience, variety, and personalisation in food choices and increased awareness of health, ethical, and environmental aspects of food consumption. However, this also led to even more complex networks of stakeholders in food production, distribution and consumption and negatively impacted the food and other associated waste production (e.g. packaging, CO_2 emissions from delivery services, etc.) (Marcantonio et al., 2021). For example, food delivery apps may promote questionable behaviours in line with their business models, such as excessive food consumption or excessive food purchases leading to food waste (Gunden et al., 2021), poor working conditions for couriers (Muszynski et al., 2022) and severe environmental impact due to excessive packaging (Jia et al., 2022).

The complexity of the food production and consumption networks has been problematised from diverse disciplinary perspectives (Gallego-Schmid et al. 2019;

Scherhaufer et al., 2018). In general, the most impactful interventions against food waste are considered to be towards prevention, by avoiding food surplus across the supply chain, reducing over-purchasing on the consumer side, and avoiding premature disposal of food (Papargyropoulou et al., 2014). Such impactful interventions require strategies and actions to be developed together with a multitude of stakeholders (Aschemann-Witzel et al., 2015). Focusing more specifically on the delivery and takeaway services, most of the studies focus on promoting recycling and waste separation behaviour or food waste reduction (e.g., Ding, 2022). Reusable food containers for such services are mostly disregarded, with only a handful of such studies attempting to explore consumers' perceptions and behaviour towards reusable containers in delivery and takeaway services (e.g., Sia et al., 2023). This is also reflected in the market, where the major efforts are towards improving packaging designs in terms of portioning, shelf life, and storability (e.g., Aschemann-Witzel et al., 2015) and technological interventions (e.g., smart packages, material innovations) (e.g., Parfitt et al., 2010).

Tackling food and packaging waste through systems thinking and design

The design literature has increasingly addressed the complex issue of food waste over the past few years. There are studies on the design of the food itself (e.g., Lee et al. 2020), the aesthetic qualities of food experience (e.g., Schifferstein et al. 2023), informing healthy food choices (e.g., Bomfim et al. 2023), behaviours and practices that cause food waste (e.g., Ganglbauer et al. 2013), and improving the storage and shelf life of food (e.g., Birhanu & Belay, 2023), among others. Recently, more collaborative processes in rethinking and reimagining food systems have begun to be explored, such as the special issue titled 'Co-Creating Sustainable Food Systems' published in the International Journal of Food Design (Wertheim-Heck & Herrera, 2023). However, there remains a gap in design literature regarding the increased use, and thus increased impact, of the food delivery and takeaway sector, which needs to be tackled from various angles. This includes not only resultant food waste, resultant excessive packaging waste and behaviour change towards waste prevention at the consumer level but also the roles of numerous stakeholders in food systems.

Different approaches to systems thinking are advocated in the design literature to understand and/or initiate societal transformations, especially in design for sustainability research. The acknowledgement of the need for systems-level change towards sustainability was reflected in this body of literature (Bhamra & Hernandez, 2021) with the emergence of systemic design (e.g. Jones & van Ael, 2022; Van der Bijl-Brouwer & Malcolm, 2020), design for sustainability transitions (e.g. Joore & Brezet, 2015; Ceschin & Gaziulusoy, 2016; Mok & Hyysalo, 2018), sustainable product-service systems (e.g. Vezzoli et al., 2015), and many others. The systems-thinking approach has been adopted in recent studies with an emphasis on promoting reusable alternatives considering design for sustainability. For instance, Long et al. (2021) explore how to apply product-service systems to reusable packaging systems in order to address the plastic waste problem in the food and household products industry. The authors

propose a strategic design tool that can classify, analyse, and generate different types of reusable packaging systems based on a combination of case studies and expert interviews. More notably, they identify 15 reusable packaging PSS archetypes, focusing on different yet focused aspects of food purchase and delivery, including trackable packaging, packaging delivery and recollection, and customer-owned packaging, among others (Long et al., 2021). Another study on reducing food and packaging waste with a systems thinking approach is on designing self-service food packaging systems by Albach et al. (2018), based on future studies and scenario planning. The authors involve design students in creating postcards from the future, depicting alternative scenarios for packaging and dispensing grain and bulk products (e.g. rice, beans, nuts, seeds, etc). They present the development and testing of a new concept of transparent containers with valves and sensors, which allow the user to choose the amount and pay the price of the product. The concept aims to reduce packaging and food waste, improve hygiene, and enhance the user experience. However, this remains a new area of inquiry in design literature and requires further exploration of the implications of systems thinking and product-service systems in designing and implementing zero-waste food systems.

Considering the main scope of the educational project focussing on sustainability, we adopted a systems-thinking approach integrating various scales of design intervention including, products, services and systems in the form of developing alternative business models. The social sustainability and systems thinking approach as emphasised by Manzini (2015, p. 17) reconsiders the existing production models and proposes the notion of 'distributed systems' by empowering local skills and rethinking the proximity of these systems including products and services to resources and points of demand. The systems thinking approach helps design students *demonstrate the viability and continuity of their design solutions* by considering actors, resources and tools and their interrelationships within a business model. This way of thinking also helps them *incorporate services about sustainability* such as prolonging lifespan, sharing, repair, reuse, upgrade and related service models. Manzini has pioneered incorporating *social sustainability* and *systems thinking approaches* in design education. The design studio education at the third-year level has been influenced by those approaches over the years. The educational project presented here showcases the means of co-developing design solutions in line with their emerging and locally relevant business models.

Educational Case: Zero Waste Food Takeaways and Deliveries Project

The 'Zero Waste Food Takeaways and Deliveries' project was carried out over 14 weeks with 85 third-year students at the Department of Industrial Design, Middle East Technical University, Turkey. The project aimed to empower students to develop sustainable design solutions for takeaway/delivered food in the form of a product family, by re-imagining the entire cycle and experience of stakeholders in the food system for healthy and responsible food production and consumption. Within this framing, the project gave emphasis to students on how to shape sustainable futures in

the context of responsible and reduced consumption and zero waste. The students were organised to work in teams (20 teams of four, one team of five: 21 in total). Two main design considerations were embedded into the brief:

1. Promoting sustainable food practices and healthy eating habits and behaviours, with sub-dimensions of *zero waste packaging*; *zero food waste*; *personalisation*; and *behaviour change*.
2. Supporting local resources and local know-how, with sub-dimensions of *local businesses*; and *local know-how and tastes*.

The brief also introduced two kick-off business models relevant to the sector:

- 'Borrow-A-Container Takeaway/Delivery Service' (BAC) describes a business lending reusable containers and accessories to customers. This model requires the business to invest in a suitable reusable product family (or else lease it from a third party) and to prepare their food and drink for customers accordingly.
- 'Bring-Your-Own Container Takeaway Service' (BYOC) describes customers who bring personally owned containers and accessories to food outlets and ask sellers to fill them with food and drink to take away.

Teams were expected to design a service system taking one of the business models as a starting point for their ideation. They were then required to design a product solution fitting within the service system. The product solution was expected to take the form of *a family of food and drink containers/accessories*. Individual components of the product family were encouraged to have variation and differentiation, such as using different volumes, combinations, and surface finishes, suited to different needs and contexts. The containers were required to be made from glass, ceramics, metals, or natural fibre composites. No restrictions were placed on materials for accessories (such as cutlery, serving aids, lids, bags, etc.), which needed to suit a wide range of functional and experiential needs. While designing product solutions, the student teams were expected to give attention to coherence and aesthetics, since the product family should integrate well with the overall business model and service design. The project was managed across the following main stages:

1. *Literature review:* Online and offline resources were used to develop baseline familiarity with a range of assigned topics relevant to the brief, including materials, food safety, trends in healthy eating, food container accessories, and solutions for portability and storage.
2. *Hands-on food experience*: Takeaways were created for various food categories (e.g. appetisers, salads, stir-fried veggies, hot meals, bakery), with teams documenting their experiences of preparing, presenting, packing, transporting, serving, and cleaning. Outcomes were shared in a class workshop, contributing to the creation of a pool of project resources.
3. *User research on takeaways:* Interviews were made with small-scale business owners/staff and customers on the university campus focusing on the food experience. Observation notes were generated for food preparation, display, serving, and storage, and potential design issues were identified.

4. *Preliminary jury:* Using 3D mock-ups, sketches, and drawings, teams presented their in-development business model, service design, and product family, for formal critique.

5. *Final jury*: Using three presentation boards, a full-scale (1:1) physical model and (optionally) a prototyped mobile application, teams presented their finalised business model and service design, their product family, and technical drawings. Teams were also required to deliver a project process portfolio at the end of the project, documenting their decision-making and the resources they had used.

To help teams in their systems thinking, three tools were introduced sequentially through the project: networked business canvas model, scenario building, and conceptual prototyping and co-design.

The *Networked Business Canvas Model* is a design tool that facilitates the exploration and design of alternative business models for distributed value creation networks (Bakırlıoğlu, 2022). It is based on the original Business Model Canvas (Osterwalder & Pigneur, 2010), but adds elements to capture the networked nature of businesses, such as the multitude of actors, networked value proposition, diverging and converging materials, and resource and value flows. This tool enables the exploration of involved actors (e.g. customers, restaurants, suppliers, delivery drivers, app/service platform owners, etc.), their capabilities, needs, and preferences, who collaborate and exchange value in complex, networked food delivery and takeaway systems. The tool facilitated an in-depth exploration of the opportunities and challenges for design intervention in the food delivery and takeaway sector by taking the business models as a starting point.

Scenario building is a skill nurtured through design education that focuses on students using their mind's eye to foresee the how, when, why, where and what of their design visions, as well as the potential consequences of design interventions on various stakeholders (Hines & Zindato, 2016). By building and testing out scenarios focusing on various actors in the food systems, the tasks they are expected to perform, and the environments in which they operate, students could reject or refine their design ideas. Scenario building encouraged students to step back from ideating around individual user-product interactions to see the 'bigger picture' of design problems and solution spaces, from multi-stakeholder perspectives.

Conceptual prototyping involves the presentation of preliminary designs that embody design intent, but which are left purposefully incomplete or at a low level of fidelity to encourage critique, interpretation, and modification during evaluation sessions (Lim et al., 2008). For this project, the conceptual prototypes included storyboards, alternative distributed value creation network maps, and physical mock-ups of product family solutions. Each of these prototypes was used to facilitate at least four co-design sessions with stakeholders in food delivery and takeaway systems. Conceptual prototyping and co-design sessions provided a practical-oriented approach to eliciting and responding to the concerns and feedback of multiple stakeholders. Teams were able to determine the

efficacy of their preliminary product solutions, service designs and business models within the food systems they explored and make adjustments accordingly.

Results

The systems thinking focus of the project enabled the reimagining of takeaway/delivery services in ways that were quite different from conventions. Project requirements involved the consideration of the diverse needs of the network of stakeholders (including but not limited to customers, couriers, chefs, producers, and food supply chain actors). The following headings describe emerging themes of alternative food delivery and takeaway service design solutions facilitated by systems thinking.

Micro-local delivery and takeaway services

Solutions under this theme conceptualised delivery and collection systems within pre-defined constrained areas or spaces, such as within singular neighbourhoods, in residential towers with a high number of residents, or within university campuses. The rationale behind these solutions was straightforward: to limit the operational area of delivery and collection services to dense enough areas/spaces to economically sustain the businesses.

Fig. 1: 'Zero' borrow-a-container food delivery service for the fitness-minded, by Yasemin Kardelen Akça, Seymur Mammadov, Yonca Sübay and Umut Zeynep Göral.

An example is Team 9's 'Zero' design solution (Fig. 1). This BAC delivery and takeaway business model operates only within a university campus, i.e. an area with a dense population. The team conceptualised operations of multiple stakeholders, i.e. different restaurants and cafes that offer wide-ranging food and drink options, customers consisting of students and university staff, students working part-time in delivery and

collection, as well as design solutions (e.g. containers, collection points). In addition to customer journey mapping, the team mapped the projected journey of the reusable takeaway/delivery containers to understand the opportunities and limitations of their potential design solutions. The final proposal included an application to track on-campus deliveries and collections, and metal reusable containers that can withstand the foreseen wear throughout the container journey. The most innovative aspect of this solution was the flexible involvement of students in the collection system - essentially forming a 'community of collectors' - in order to sustain an effective collection process.
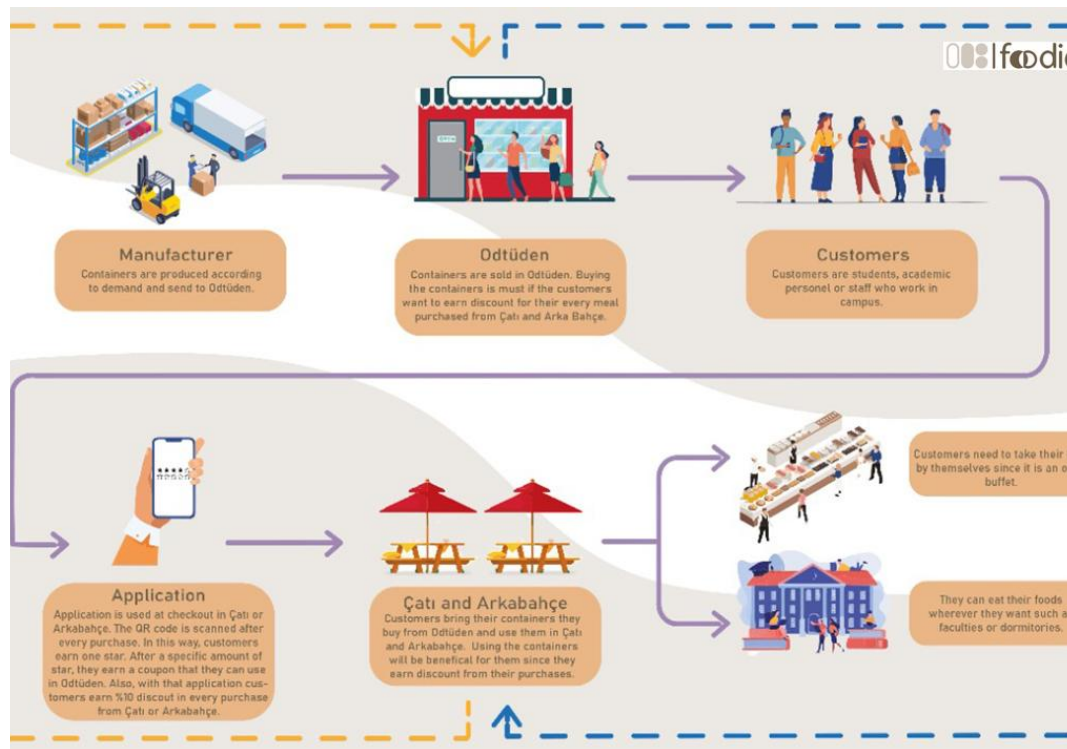

Fig. 2: 'Foodie' bring-your-container takeaway service for the Middle East Technical University campus, designed by Gökay Aydın, İlke Başpınar, Melis Ergün and Merve Nur Sözen.

A similar pattern existed for teams working on BYOC business models, where a standardisation across a dense network of restaurants and cafes within limited areas (e.g. campuses) was also observed. For example, Team 3's 'Foodie' design solution (Fig. 2) involved the sale of standardised reusable containers that can accommodate the wide-ranging food and drink offerings on campus. By analysing the different types of food and drinks available in different restaurants and cafes, the team developed a container range with standardised measurements that allowed universal use across the campus. They also identified sales channels (i.e. METU bookstore) appropriate to the campus community and devised various incentives for adopting the product family.

Third-party container provider services

Solutions under this theme were concerned with the additional resources required to manage delivery and collection services which may not be economically sustainable

within the confines of singular restaurant businesses. Students conceptualised alternative service design solutions to the existing third-party delivery services by intertwining two service layers: delivery of food and drink, as well as collection of used containers ready to be introduced back into the service chain. By managing the container delivery, collection and maintenance (i.e. cleaning, repairing, replacing) on behalf of a network of restaurants and outlets, these external services could be economically sustainable and reduce CO_2 emissions by streamlined delivery and takeaway routes, reducing the need for double trips (i.e. a single trip can be used for delivery and collection).

Team 15's 'Soogana' is a third-party provider service solution (Fig. 3) focussing on Asian cuisine with a unique brand identity. The maintenance and cleaning services are provided by this systems-thinking service solution. It also involves a recycling system through which any broken containers are separated and sent to another service provider to reintegrate the damaged containers into the system of production.
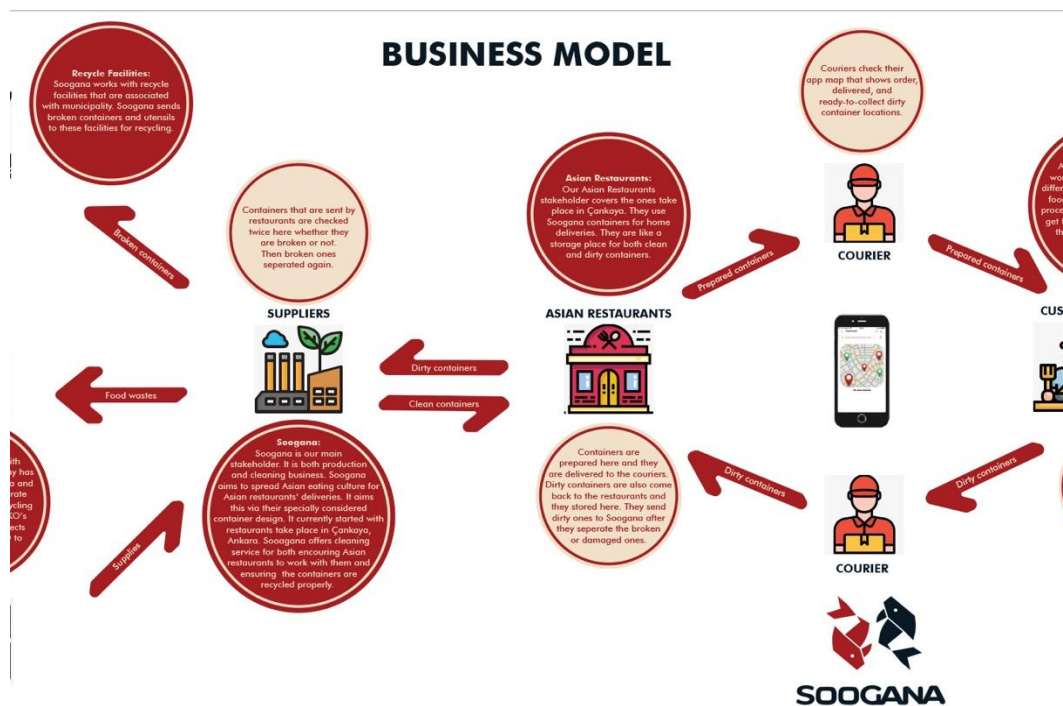

Fig. 3: 'Soogana' third-party container provider service-system solution, designed by Ahmet Aksoy, Deniz Kıyğı, Mervegül Öksüz and Sude Pursin

Team 1's 'Götür' is an example of a third-party container provider service solution (Fig. 4) which provides food and drinks containers to local restaurants. The service maintains and cleans the containers through an integrated system involving a container supplier, a network of restaurants, and individual customers. The solution promotes sustainable transportation modes (e.g. electric vehicles) while delivering and collecting containers. In line with this business service model, *Team 1* proposes a modular and personalised container solution, through which individual components could be brought together in different configurations depending on the needs and preferences of local restaurants.
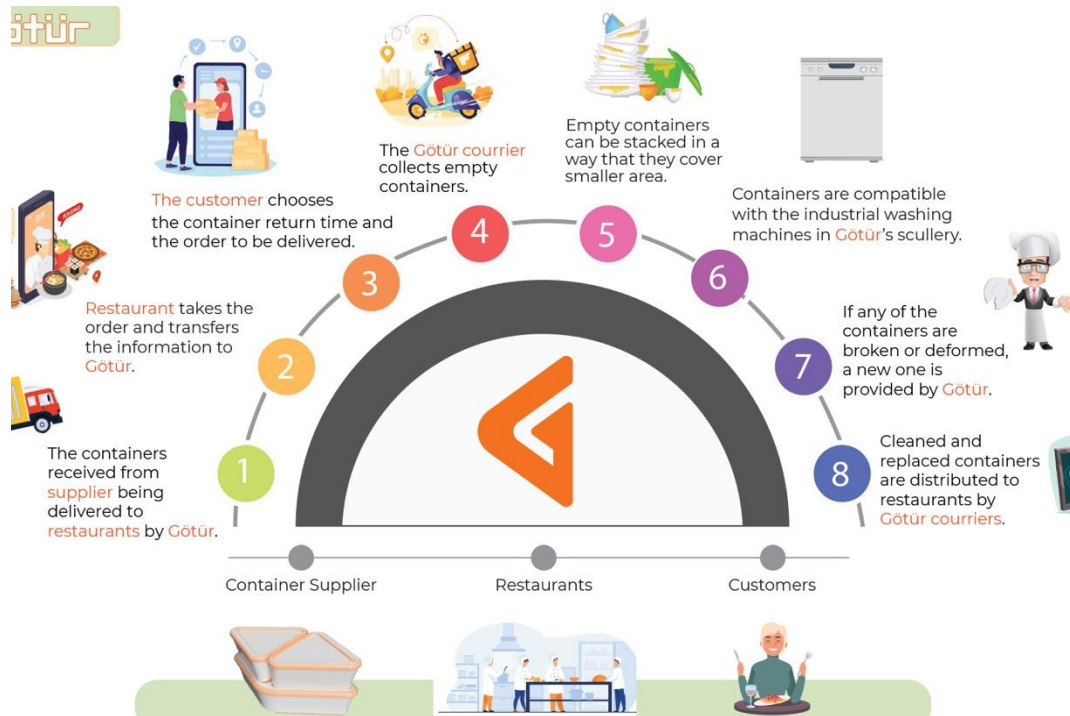
Fig. 4: 'Götür' third-party container provider service-system solution, designed by Afra Sevil, Barış Balkan, Ceren Keklik, Raziye Zalgı and Zeynep Nur Hasıripi.
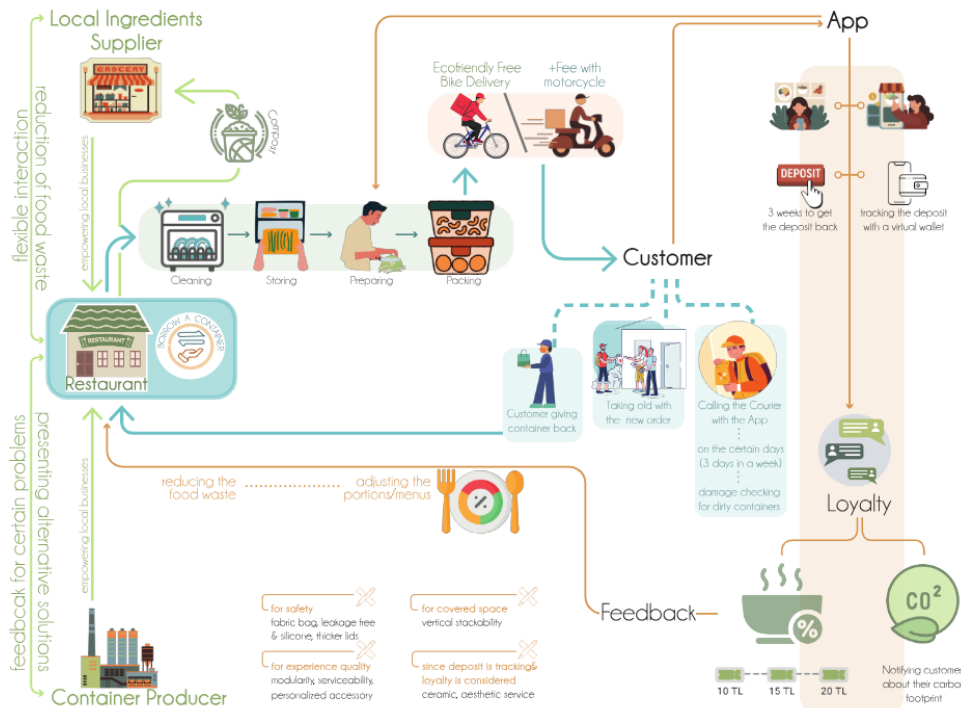

Fig. 5: The system map of 'Mitterra' borrow-a-container food delivery service with diverse stakeholders, designed by Beyza Eylül Ergün, Demet Çamlı, Melis Uludağ and Sudenur Ortak.

Implications of systems thinking in designing zero-waste deliveries and takeaways

Team 10's 'Mitterra' is an example of a more complex systems-thinking solution that involves diverse stakeholders and presents the relationships between them, including

local ingredient suppliers, the container producer and the local restaurant adapting a BAC food delivery service (Fig. 5). Within this business model, an app design solution demonstrates how the system could be sustained in the long term by applying loyalty schemes promoting sustainable behaviour choices (e.g. choosing an eco-friendly bike delivery option, informing users about their carbon footprint, providing feedback to the restaurant on food waste, adjusting the portions). Team 10's solution is a good example of how deploying a systems thinking approach can enable the conceptualisation of food systems beyond the immediate focus of the project, i.e. expanding into food delivery services and facilitating the development of more holistic sets of design interventions.

Table 1: Analysis of systems thinking and design solutions.

Team	BAC	BYOC	Micro-local delivery and takeaway services	Third-party container provider services	Observation on System Thinking
1	✓		–	Offers containers to local restaurants, managing delivery, collection and cleaning.	Eco-friendly delivery via electric vehicles; customers choose container collection time.
2		✓	Pick up food with containers in a specially designed bag.	–	Containers available at market; customizable, discounts for BYO customers; promoting local farmers.
3		✓	Eat-in or pick up food with containers in a specially designed portable bag.	–	Containers produced to demand for sale at campus shops; usable in all eating places with discounts for customers bringing their own; earn additional coupons via app for more discounts/freebies at campus shops.
4	✓	✓	Pick up food with containers arranged for portability.	–	Borrowers return items to designated 'return bins' on campus for collection by the shop for cleaning, scanning them with a QR code; earn a free coffee with a loyalty card: buy five, get one free.
5	✓		Online orders only, motorbiked couriers deliver within a 10km radius.	Unified delivery, collection, and cleaning service.	Endorsement of local food producers; customers receive deposit refund upon container returns.
6	✓		Campus-based; order through the app for pre-prepared food pickup or eat-in at temporary office-like space.	–	Endorsement of female farmers in the local district; container collection by café staff at office doors, done on foot and guided by app notifications.
7	✓		Order via app, delivery by courier.	–	Locally owned farm for seasonal, homemade food; partnerships with local workshops & factories for packaging and containers; 2-day container return period, free collection; food waste as fertiliser; in-app promotions.
8	✓		Order food via app from contracted restaurants.	Container rental agency with courier service, providing delivery, collection & cleaning.	Containers can be kept for a limited period if food is not yet consumed.
9	✓		Campus-based: main delivery, by courier companies, assisted by students at pick-up points.	Delivery from local restaurants via couriers to campus pick-up points; returns by customer, courier, or students.	Customizable portions; monthly food waste-saved info; app-based container tracking for deposits; student incentives.
10	✓		Order food via app for bike delivery or pay a fee for motorbike.	–	Local groceries for plant-based food supply; virtual wallet tracking for deposits/returns; incentives for loyal customers; carbon print info provided.
11		✓	App-based restaurant/food selection for self-pickup.	–	Discounts for new container buyers and BYOs; reducing unnecessary waste; cleaning by the customers; supporting local producers; environmental awareness.
12	✓		Campus-based restaurants' food delivery to campus area.	Courier delivery; manufacturer (separate company) responsible for repairs and cleaning.	Returns by customer to designated stations; app-based container tracking;
13	✓		Order food via app from multiple cafes.	Delivery and container collection by electric motorbike couriers via shortest route.	App-based container tracking for deposits; higher cost for deformed and uncleaned returns.
14	✓		Order food via app from small food kiosks, where ingredients are supplied externally.	Food deliveries from kiosks to customers by couriers, including container collection.	Customers add finishing touches to food before eating.
15	✓		Order food from multiple restaurants.	Food deliveries and container collection by a courier.	Supplier manages container production & cleaning; food waste goes to recycling; damaged containers recycled if irreparable.
16	✓		Campus-based restaurant food micro-local delivery with a food cart; food kiosk and mobile track with take-away.	–	Container returns by customers; app-based container tracking for deposits; app-based deposit tracking; loyalty program offers free meals and special deals; local ingredient supply; leftover food collected for composting.
17	✓		App-based restaurant/food selection for self-pickup and return.	–	Membership-based daily food box receipt; ingredients from local suppliers; customers receive clean containers when returning dirty ones; container cleaning at restaurants.
18	✓		Customers eat in or take away.	Local delivery from orchards via couriers; customers return containers or leave them at collection cabinets for pickup.	Reusable container cleaning and food waste composting by the orchard; app-based reminders for returns.
19	✓		Order food via app.	Motorbike courier delivery; returns by customer or courier.	Endorsement of local farmers; warehouse provides containers to restaurants; cleaning handled by restaurants; app-based deposit tracking for containers.
20		✓	Pre-order food via website or in-store for take-away.	–	Endorsement of women's cooperative; containers available for purchase individually or as a set with a carrying bag.
21	✓	✓	Customers collect their food.	–	Endorsement of local farmers; food waste used as fertiliser; container deposit refund upon return; container purchase option.

Table 1 highlights the two emerging themes amongst the student projects (i.e. micro-local delivery and takeaway services, and third-party container provider services), alongside the impact of systems thinking in the final design outcomes. Nearly all teams (20 out of 21) adopted micro-scale localisation as their starting point, and developed solutions focused on e.g., business centres or specific neighbourhoods. Some (10 out of 21) reconceptualised and expanded typical third-party delivery services to involve reusable packaging and organised collection. Others reimagined collaboration among small businesses and proposed local business food delivery offerings through food marketplaces or similar. Each of these directions revealed a diverse set of challenges centred on transitioning from single-use packaging consumption to longer-life solutions and implicit changes in professional practices and consumer behaviour. In this way, packaging was extensively reimagined for food preparation, portioning and pricing, food type-specific delivery considerations, durability and compatibility according to the delivery vehicle (e.g. bike, motorbike, on foot), serving at home or office, collection after consumption, and longevity according to maintenance and cleaning processes. Furthermore, the teams generally endorsed local food producers, devised app-based container tracking and deposit management, incentivised loyal customers and container returns, and promoted waste reduction throughout the food systems they conceptualised.

Conclusions

In conclusion, beyond a user-centred approach, the paper illustrates the value to be gained in taking a whole systems thinking approach in educational design projects, with the aim to uncover and respond to the diverse needs and preferences of various stakeholders. One of the main ways to achieve this, which separates the work from more conventional design activity, is the integration of business models into the problem/solution space of the designer. Business models require designers to extend their thinking to practical and entrepreneurial factors that go beyond individual product-user relations, as well as beyond the narratives that surround existing and conventional solutions. The combined use of the networked business canvas model, scenario building, and co-design activities based on conceptual prototypes, provided the students with a powerful suite of tools to deploy systems thinking, which helped them reach innovative and potentially impactful solutions. In the area of take-away food and drinks packaging, the suite of tools allowed students to define and comprehend the 'bigger picture' of opportunities and constraints at play, covering the spectrum of activities for takeaway food and drinks: e.g. ordering, preparing, carrying, delivering, borrowing, serving, eating/drinking, returning, and cleaning/maintenance. In the absence of a systems thinking approach, we predict that design solutions will be more isolated and prone to obsolescence, missing out on the key interactions and long-term opportunities that arise when a network of stakeholders is properly considered.

From an educational perspective, the project provided a practical and structured way for students to understand the necessities and practicalities of reaching sustainable

design solutions in complex systems with various stakeholders, which should provide a good foundation for their professional careers. By intentionally integrating systems thinking into a sustainable design solutions project, the students gained practical skills and developed a better understanding of the issues surrounding single-use food packaging. This also helped them become more aware of the complex relations, needs and preferences of various stakeholders involved in the system, and develop the capabilities to align interests through designing products and services by reimagining whole systems.

Based on our observations, some of the student teams directly benefited from their business model while developing design solutions. Whereas for others, it appeared to be a separate phase rather than an integrated one. We believe this is related to an unfamiliarity with the scale of the solutions involved, which is much greater than the individual product scale that students had been used to. In future projects that aim to address systems-level change, additional design exercises could be planned which aim to develop the two strands (idea generation and business model development) simultaneously through a more interconnected approach. Nonetheless, a valuable outcome and contribution of this educational project was that the student teams were compelled to explore various design interventions beyond physical products (e.g. applications, contexts, spaces), contributing to complex, connected, systems-level design solutions to reflect on the multifaceted dimensions of sustainability.

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All authors contributed equally to the conceptualization, methodology, and writing of this manuscript. The author list was created according to alphabetical order based on authors' surnames.

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