International Journal on Robotics, Automation and Sciences

Design for Additive Manufacturing Optimized Vertical Lunchbox Design

Chockalingam Palanisamy*, Deo Yue Ing Duvall, Yeo Tian Zhenn, Maliha Syeda Fairuz, Chia Shyan Lee and Cheng Zheng

***Abstract* – The vertical lunchbox (VL) project, propose an innovative and functional solution for movement. Traditional lunchboxes often fail to meet the diverse needs of today's consumers, including the desire for convenience, portability, and meal freshness. This project uses the advantages of additive manufacturing to create a lunchbox that not only offers practicality and usability but also incorporates distinctive features tailored to present lifestyles. The design process employs a concept of Design for Additive Manufacturing (DfAM) and Design for Manufacturing and Assembly (DfMA) principles. These concepts enable the development of required features and at the same time reducing assembly time and improve the functionality. Important features of the vertical lunchbox include customizable compartments that can accommodate ice packs, the lid that can be used as a handphone holder, and removable containers for easy cleaning. These features are catering to the needs of busy professionals and students. Parametric modeling and topological optimization helped to ensure that the lunchbox design is appealing and at the same time lightweight and strong. The adoption of 3D printing technology enabled faster production processes with required dimensional accuracy. Test results indicate that the vertical lunchbox meets most of the user requirements. The important features such as a secured locking and snap-fit lid design ensured the reliable transport containers for carrying food. In Addition, the project proved that additive manufacturing can be used for time to market approach of the product development. Finally, the vertical lunchbox project demonstrates how advanced manufacturing techniques can transform traditional product design to meet modern consumer needs.**

Keywords—3D modelling, Vertical Lunchbox, 3D Printing, Design for Additive Manufacturing, Design for Manufacturing and Assembly, Topology Optimization.

I. Introduction

In today's fast-paced world, convenience and functionality are paramount in consumer products. With growing urbanization and increasing time constraints on individuals, the demand for innovative solutions to daily challenges is essential. The evolution of food packaging, focusing on sustainability,

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International Journal on Robotics, Automation and Sciences (2025) 7, 2:125-129
https://doi.org/10.33093/ijoras.2025.7.2.13
Manuscript received:18 Feb 2025 | Revised: 12 Apr 2025 | Accepted: 29 Apr 2025 | Published: 30 Jul 2025

Published by MMU PRESS. URL: http://journals.mmupress.com/ijoras

innovation, and the integration of traditional methods with modern technologies, are very important [1]. Traditional lunchboxes often fall short in addressing these contemporary needs, prompting the exploration of innovative designs that capitalize on advancements in manufacturing technology, durability, reusable with a focus on material care and cleaning practices are much more important [2]. Beyond basic storage, modern designs incorporate advanced features such as secure compartments for utensils, leak- proof seals, and sections for ice packs to regulate temperature [3]. These features make it easier to store and handle food while maintaining its quality throughout the day. Additionally, features such as airtight seals and spill-resistant designs further enhance the safety and reliability of these products [4], [11].

Additive manufacturing is one of the groundbreaking technologies in product design and manufacturing. Product customization and meeting user requirements are possible with additive manufacturing than traditional methods. This project, focused on the development of a vertical lunchbox, aims to use the advantage of additive manufacturing unique features by integrating innovative design principles with the capabilities of additive manufacturing.

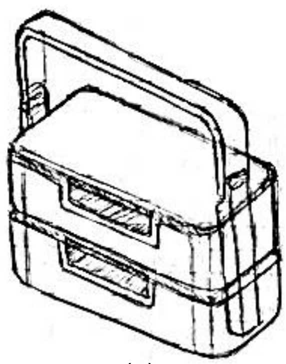
Felix and Durate [5], said lack of variety of lunchbox products in the market for modern day consumers. They developed a modular lunchbox with integral construction, allowing separate sections for different food items. The recommended combining functionality with appeal can enhance user experience and promote healthier eating by carrying home food. The vertical lunchbox design works towards addressing the many users need such as: ease of use, portability, and the ability to maintain food freshness. With increased emphasis on healthy eating and meal preparation, it is crucial to create lunchbox solutions that align with a modern-day lifestyle while remaining practical for day-to-day use.

Design for Additive Manufacturing (DfAM) and Design for Manufacturing and Assembly (DfMA) concepts used in this vertical lunchbox design. These principles helped in optimizing parts designs for 3D printing, reducing assembly time while packing and unpacking and improving functional performance. By giving importance to part geometry and ease of assembly, this project aims to create a product that is effective on its purpose by faster and efficient method to manufacture the parts and assembly the parts. In addition, the 3D modeling and topological optimization techniques ensured that the final product is lightweight yet structurally strong, addressing both appealing and functional considerations. This method aligns with the emerging trend of utilizing advanced software tools to enhance product design, facilitating the development of innovative solutions that are aligned with modern consumer expectations. By addressing the practical needs of modern-day users and giving importance to functionality, this project contribute significantly to the portable lunch solutions.

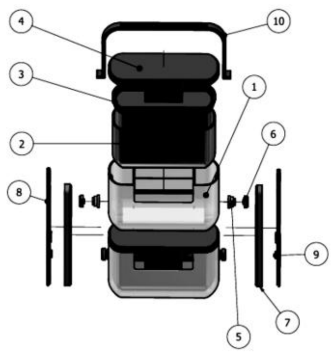
II. Methodology

A. Conceptual Sketching

The concept of the vertical lunchbox is determined to address modern-day customer needs, such as portability, organization, ease of cleaning, and food security. The problem statements identified the key design requirements such as: i. Portability, ii. Ease of setup, iii. Compact, iv. Lightweight, v. Effective food sealing, vi. To maintain food temperature, vii. Ease of cleaning, viii. Cost-effectiveness. Figure 1 (a) shows a concept sketch developed to visualize the intended product functionality from design requirement. The early design featured a twin-stacked lunchbox with a handle for easy transport. This design allowed for a change in orientations between vertical and horizontal positions to provide flexible usage. A key innovation in the design was a sliding mechanism with a latch system, enabling the lunchbox to transition seamlessly between orientations. The initial sketches outlined the rough dimensions and mechanisms for interlocking the components. Furthermore, early considerations were given to container encasement, sealing mechanisms, and hinged latches, ensuring that the design would remain functional and secure. The conceptual sketches also introduced ribbings to enhance structural integrity while minimizing material usage.



(a)



No	Qty	Name
1	2	Enclosure
2	2	Container
3	2	Press Lid
4	2	Latch Lid
5	4	Slider
6	4	Slider Cap
7	2	Slot Guide
8	2	Slot Cover
9	2	Hinge Latch
10	1	Handle

(b)

FIGURE 1. Vertical Lunchbox (a) Conceptual sketch (b) 3D model.

B. 3D Modelling

Figure 1(b) shows the design of the vertical lunchbox. The model was developed using Autodesk Inventor. Pranoto et al [6], aimed to reduce the hassle of carrying multiple containers including a drinking water container ensures that both food and drink conveniently carrying. They align product design with consumer needs, ensuring functionality and ease of use. The 3D modeling process began with creating individual components such as the container, enclosure, sliding mechanism, and latch system, ensuring they fit together seamlessly. The final parametric design was exported for FDM 3D printing, where custom print settings were optimized to balance strength, weight, and print efficiency. This digital workflow streamlined the development process, enabling rapid prototyping and iterative improvements.

C. Topology Optimization

Implementing Design for Additive Manufacturing (DfAM) principles to enhance printability and structural integrity. To improve strength and reduce weight, topological optimization was applied using Autodesk Inventor's Shape Generator tool. This process allowed for a 50% weight reduction in the handle design while maintaining structural integrity. Lu and Luo, [7], created a framework on mobile lunchbox according to users prioritized functionality and designers focused on aesthetic designs. The lunchbox design is viewed as a reinterpreted tradition to maintain cultural practices in a modern context.

D. 3D Printing

All components were fabricated using an FDM-based Creality Ender-3 V3 3D printer, with print settings tailored for each part. Development of prototypes is important for testing [8]. The following parameters were used. Layer Thickness of 0.2 mm number of shells based on the need for structural integrity and strength, Infill density, selected to balance the weight and strength of each printed part, support type chosen based on the geometry of the parts to facilitate easier removal post-printing, heat bed temperature set within the range to aid in adhesion of the material to the build platform. The material used for 3D printing was Polylactic Acid (PLA). The nozzle temperature used is between 190°C to 220°C; bed temperature set between 50°C and 80°C to prevent warping and ensure stable printing conditions.

E. Postprocessing and Assembly

After printing, components were removed from the build plate. Minimal post-processing was used to remove the support structures from overhangs and deburring of sharp edges for better fitment. All printed parts were then assembled and tested for their functionality, ensuring that components fit properly and operate as intended. General product functionality testing was conducted by checking the sliding mechanism's latch locks followed by switching the orientation modes of the lunchbox from vertical to horizontal. The results were found to be satisfactory, and the product functioned well as intended.

One of the important features of the vertical lunchbox is its dual orientation. Figure 2 shows the vertical and horizontal arrangement of the vertical lunchbox. This flexibility ensures that the lunchbox fits into various situations with good use of space. When carried vertically, its compact form allows it to fit into most bags, making it an ideal choice for all. On the other hand, its horizontal orientation makes it perfect for placement on flat surfaces such as tables for eating. The transition between these orientations is smooth and effortless, improving its practicality and appeal.

The lunchbox design has a removable handle, which further increases its versatility. This feature supports the users who need portability without compromising on space.

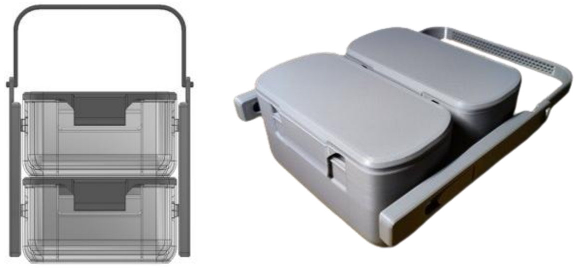

(a) (b)

FIGURE 2. (a) Vertical Orientation (b) Horizontal Orientation

III. RESULTS AND DISCUSSION

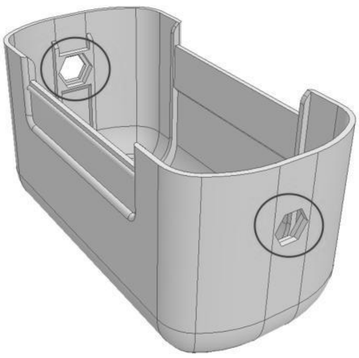
To maximize the potential of additive manufacturing, design for manufacturing and assembly (DfMA) principles were applied throughout the product's development. Key design for additive manufacturing (DfAM) strategies were implemented to enhance efficiency, structural integrity, and print quality.

The handle's ergonomic design ensures a comfortable grip, making it easy to carry even when the lunchbox is fully loaded. Another feature of the VL is its dedicated compartment for utensils. This lunch box includes a specifically designed section to store forks, knives, or other utensils, keeping them organized, and readily accessible. This feature helps the dining experience, by ensuring that all necessary utensils are within reach.

The latched lid of the lunchbox securely seals the contents within, and it can also be transformed into a hand phone holder. This feature caters to modern lifestyles, allowing users to enjoy their meals while staying connected or entertained. This design ensures that the lunchbox aligns perfectly with the needs of today's tech-savvy users. The Vertical Lunchbox incorporates a compartment for an ice pack. This compartment can be placed on either the top or bottom of the lunchbox, to maintain the freshness of the food stored. The removable food containers allow users to clean them or even heat or freeze them as needed. This modular design simplifies meal storage and allows for quick switching between meals, enabling users to customize their lunchbox to suit their preferences and schedule. The lunchbox is designed to accommodate a variety of foods in quantities suitable for a typical daily intake.

A. Hexagonal Holes for Fitting

Traditional circular holes were avoided in favor of hexagonal profiles due to potential layer discontinuities caused by overhanging sections as shown in Figure 3a. The hexagonal shape was chosen because its 60° angled sides fall within the recommended 45° overhang limit, reducing the need for extensive support and improving print accuracy. This design approach ensured tight-fitting, interference-tolerant connections, particularly for fasteners. Rounded edges for easy printing: The containers and enclosures required rounded edges for both aesthetic and functional reasons. However, directly applying large fillets would have created overhangs, requiring additional supports that could negatively impact surface quality. To address this, a two-step approach was used: A 45° chamfer was applied at the bottom edge, allowing it to be printed without support. A large fillet was then added to the upper chamfered edge, achieving the desired rounded effect while maintaining print efficiency as shown in Figure 3b.



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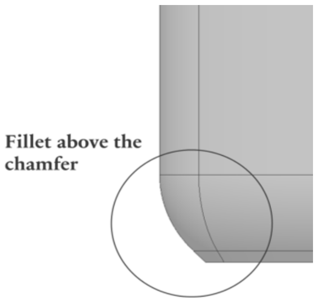

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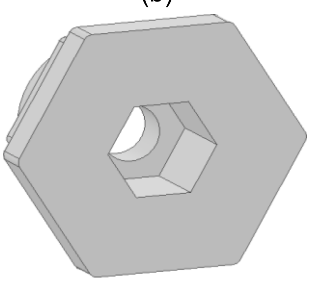


(c)

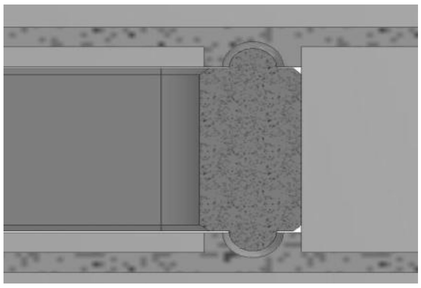
FIGURE 3. (a) Hexagonal Holes in Enclosure. (b) Rounded Edges on Containers (c) Hexagonal Holes for interference Fit

B. Interference Fit Components

To enhance assembly reliability, press-fit connections were incorporated into the design. Figure 3c shows a hexagonal hole assigned with interference fit tolerance based on standard M3 nut dimensions. This allows the nut to be used as a threaded insert enabling bolt to reliably fasten to the part. This method ensured consistent, durable connections while maintaining ease of assembly and disassembly.

C. Print-in-Place Design:

Figure 4a shows a ball hinge joint with a 0.4 mm tolerance that was incorporated to allow smooth movement while ensuring proper fitment. This approach not only streamlined post-printing assembly but also reduced overall manufacturing time and part count. Slot Cover and Latch subassembly shown in Figure 4b, made with print-in-place strategy was applied to eliminate the need for separate fasteners and reduce assembly complexity



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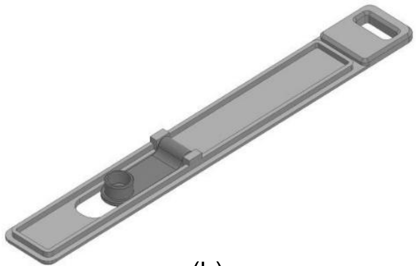

(b)

FIGURE 4. (a) Ball hinge latch joint. (b) Latch and Slot Cover Subassembly.

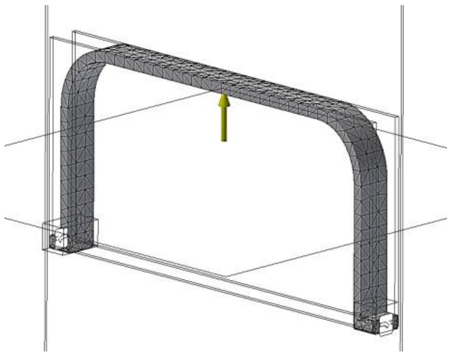

FIGURE 5. Topology Optimized Handle.

D. Topological Optimization

To minimize material usage while maintaining strength, topological optimization was implemented using Autodesk Inventor's Shape Generator tool (Figure 5). In this method a mathematical algorithm to distribute material efficiently based on applied loads and constraints. In the handle's design, a target weight reduction of 50% was achieved by strategically removing unnecessary material while ensuring structural integrity and durability. This is in line with the findings of Ahmed et al, 2021 [9]. The tool generated an optimized shape, removing material in low-stress areas while maintaining reinforcement where necessary. The final optimized shape was then integrated into the part model for fabrication.

E. Assembly Optimization

The design was refined to ensure all components could be easily assembled and disassembled with minimal effort. The sliding mechanism and locking system were tested through virtual simulations in Autodesk Inventor, ensuring seamless functionality before physical prototyping. The interlocking components, snap-fit lids, and guided slots contributed to a well-structured, user-friendly assembly.

The vertical lunchbox (VL) demonstrated the value of additive manufacturing (AM) in developing functional consumer products. The manufacturing and assembly process proved 3D printing, offering a cost-effective and at the same time durable solution. These results align with the findings of Zhou et al. [10], who emphasized the critical role of optimized packaging design in enhancing functionality and user satisfaction.

IV. CONCLUSION

The vertical lunchbox (VL) project investigates the product design and development using 3D modelling and 3D printing. This project shows how 3D printing can be used to make user-friendly products for today's needs. The design process focused on understanding users' requirements and preferences. Features like a latched lid that act as a phone holder and a special compartment for ice packs were added to make the lunchbox more user friendly. These features meet the modern consumers multitasking while taking food.

The project used a concept of design for additive manufacturing and design for assembly. This method reduced design and assembly time and improved the looks and strength of the parts. The "print-in-place" concept simplified manufacturing by eliminating the need for extra fasteners. Fused deposition modeling (FDM) technology, with carefully chosen settings, ensured the printed parts were accurate and functional. Testing showed the lunchbox worked well for its purpose. The locking mechanism and snap-fit lids proved reliable and practical. Although there were small size differences in the printed parts, they were within acceptable limits, showing the production process was effective. The project also highlighted the use of advanced tools like topological optimization to improve the design. This study demonstrates how 3D printing can be a sustainable and cost-effective solution for small-scale manufacturing of everyday products like the vertical lunchbox.

ACKNOWLEDGMENT

The authors would like to express gratitude to the FET and MMU Press, Multimedia University, for their moral support.

FUNDING STATEMENT

This design work did not receive any funding from support agencies.

AUTHOR CONTRIBUTIONS

Chockalingam Palanisamy: Conceptualization, Supervision, Methodology, Validation, Writing – Review & Editing;

Deo Yue Ing Duvall: 3D Modeling, 3D Printing, Draft Writing – Original Preparation, Review & Editing;

Yeo Tian Zhenn: 3D Modeling, 3D Printing, Draft Writing – Original Preparation;

Maliha Syeda Fairuz: 3D Modeling, 3D Printing, Draft Writing – Original Preparation;

Chia Shyan Lee: Writing – Review & Editing;

Cheng Zheng: Writing – Review & Editing.

CONFLICT OF INTERESTS

No conflicts of interest have been disclosed.

ETHICS STATEMENTS

There are no ethical considerations to declare. This work does not involve human subjects, animals, or data from any social media platforms.

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