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PAPER

Embedded components design strategy framework for fused deposition modeling system

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Keywords: embedded component, design framework, fused deposition modeling, case study

Abstract

This paper proposed a framework for 3D printing of embedded objects specifically for the Fused Deposition Modeling (FDM) system. The main problem revolves around the difficulty of the additive manufacturing process to fully manufacture a product that can be used immediately after the printing process, thus creating the need for embedded component design to be utilized in the process. The framework was utilized to reduce components and assemblies to improve product design. To ensure environmental sustainability, the framework emphasizes materials used to make recyclable items. Design Process Flow, Design Knowledge, Key Enabling Technologies, and Design Application were used to create a four-layered design framework to tackle embedded product design challenges. The framework's robustness and effectiveness were compared using three case studies: electric shaver, remote control and nintendo switch. The framework proposed a blade-interchangeable product for the electric shaver. In the second case study (remote control) the cover's flexibility with similar sizes makes it reusable. In the third case study (nintendo switch), every part is interchangeable with numerous styles and designs, allowing the user to autonomously change to the desired pattern without external support. With its various features, the framework shows potential in reducing development time, cost, and resources to aid the embedded component design strategy and printing for the FDM process.

1. Introduction

Additive manufacturing (AM) is the construction of a three-dimensional object from a CAD model that can be done in a variety of processes in which material is deposited and, typically layer by layer [1]. This sparked the next generation of production processes. Reduction in material waste compared to traditional production methods and lower energy consumption, which helps to improve the sustainability are some important AM advantages [2]. Traditional manufacturing techniques are subtractive, leaving a lot of waste material behind. In addition, 3D-printed parts are designed without molds, so they require less material, which means less waste.

AM also offers customization, expedited prototyping, inventory stock reduction, legacy components, manufacturing and assembly, part flexibility, part dependability, production flexibility, and supply chain improvements [3, 4]. These characteristics assist 3D printing of parts such as for the aeronautical, automotive and other complex engineering industries. AM's environmental freedom makes it suitable for medical and bespoke products when production volumes are relatively low or the parts are small and would have high material waste if traditionally manufactured [5].

AM's downsides include poor printed parts surface quality, slow build rates , higher cost of production and post-processing costs [6]. Since they need reliable parts, most AMs are ideal for aerospace, consumer products, energy, medical, and transportation [7]. The aerospace application requires a reliable product due to vacuum and pressure [8]. Thus, AM is the greatest solution since it delivers complex, integrated components with greater strength, which the industry needs. All consolidated designs require the least material and total weight rebate, crucial in aircraft [9].

AM can save energy, waste, and materials compared to traditional manufacturing [10]. This is essential because AM component wear characteristics have been little studied with few exceptions. This technology can also boost energy production, allowing for more design freedom and faster manufacturing. This helps determine and improve AM part wear [11]. Integrated components and multi-material assemblies are hard to disassemble for recycling and disposal, making the problem worse [12, 13].

Additionally, 3D printing is the umbrella word encompassing layer-by-layer manufacturing technology known as AM, of which fuse desposition modeling (FDM) has been widely adopted by many businesses. As an additive process, FDM may achieve industrial standards. There are many AM cost estimates, but no simple way to compare procedure profitability [14].

AM highlighted the benefits of incorporating embedded components and printed assemblies. The ability to stop the printing process mid-print and embed the components into cavities that have already been created is a valuable feature of several current additive manufacturing systems [15]. Printing resumes when the component is implanted, and the printer covers up the area around the inserted component and the void. Component embedding makes produced parts more useful and turns them from passive parts into active systems. It is possible to embed various items, including mechanical and electrical components. For example, battery-powered devices, computer chips, sensors, and actuators are all potential objects [16].

Conversely, printed assemblies are often not taken apart for regular maintenance or repair. This results in an increase in both the cost and the amount of waste generated by the product throughout its lifespan. This is particularly noteworthy because, apart from a few rare cases, there is no effort being made to assess and enhance the durability characteristics of AM components. The issue is worsened by objects that have embedded components and multi-material assemblies, as they are challenging to dismantle for recycling and disposal [17].

Nassar and Dahiya (2021) researched the components that influence the construction of embedded 3D-printed, planar, and out-of-plane circuits using FDM [18]. In this study, they created a printed circuit and 3D linkages with the PIC microcontroller. In addition, the impact of printing settings on the selected Electrifi conductive copper-based filament and the effects of lateral and longitudinal printing orientation on the conductivity of the printed tracks are also analyzed.

The implementation of embedded components in design tools is a highly challenging aspect. Due to the predominance of 2D CAD tools, the process of accurately designing with integrated components and modeling the appropriate connection type can prove to be arduous and time-intensive [19]. Frequently, a substantial quantity of documentation is required to be provided to manufacturing providers to prevent errors and guarantee that the boards are made according to the intended specifications [20]. The effective and prosperous utilization of integrated components commences with the product planning phase.

Offering electrical functionality during AM is a fascinating new approach. An investigation to compare approaches for combining 3D dispensing, an extrusion-based AM process, with electrical component embedding. The best strategy is chosen based on surface quality and accuracy from six options [21]. Long-term reliability tests (humidity and thermal shock testing) focused on electrical contacts between printed tracks and embedded electronic components to confirm the selection. The embedded method and cavity design did not affect printed electrical track durability. Finally, a three-dimensional enclosure with an acceleration sensor shows real-world applicability [22, 23].

In the future, AM will replace subtractive manufacturing to eliminate waste and speed up part creation. Because it takes time to produce parts, AM is unlikely to replace subtractive or traditional production. For simpler pieces, subtractive production is still employed, while additive manufacturing is becoming more popular for smaller batches of more complex items [24]. The effect of the FDM print parameters (nozzle, bed temperature, and layer height) on the conductivity and piezoresistive response under cyclic loads of FDM 3D-printed strain sensors have been studied [25]. Composites made of thermoplastic polyurethane and multi-walled carbon nanotubes were used in this research. This research paves the way for fresh uses of embedded piezoresistive 3D-printed sensors, where dynamic measurements are crucial. To prevent module waste, FDM components must be lightweight so they may be quickly replaced by the application [26].

The novelty of the presented work is, the embedded components design strategies framework will focused specifically for the FDM systems. The aim will be on refining design strategies with a framework to overcome embedded components design challenges. The significant of the framework proposed was utilized to reduce components and assemblies to improve product design. To ensure environmental sustainability, the framework emphasizes materials used to make recyclable items. In addition, the application-specific material is chosen to prevent part reduction reliability. Design Process Flow, Design Knowledge, Key Enabling Technologies, and Design Application were used to create a four-layered design framework to tackle embedded product design challenges specifically for the FDM system.

1.1. Design for additive manufacturing (DfAM)

Design for Additive Manufacturing (DfAM) is the art, science and skill to design for manufacturability using 3D printers, is different from subtractive manufacturing and injection molding [27, 28]. Manufacturers use AM methods is used to improve product design by reducing the number of components and assemblies in DfAM. The design freedoms provided by DfAM, such as function integration and structure reduction, have not been thoroughly investigated [29].

DfAM introduces a new perspective and 3D printing technologies such as FDM, Selective Laser Sintering, and Selective Laser Melting have specific properties that must be considered during design [30, 31]. It is necessary to research novel DfAM processes to fully use the manufacturing capabilities of AM for complex geometry, multi-material, multi-scale, and multi-function applications [32].

Haruna & Jiang (2022) proposed a framework based on the Fuzzy Bayesian Network for DFAM decision-making. They investigate the potential adaptability of DFAM. Twenty impact factors were encapsulated from experts' experience and existing literature. A robot arm claw was used to show the effectiveness of the approach. The results showed that FBN could be used to guide DFAM adaptability in the manufacturing industry [33].

Bikas *et al* (2019) presents an innovative method that utilizes force-flow to enable DfAM at different scales - macroscale, mesoscale, and microscale. The aim is to integrate force-flow-based design with AM in a cohesive manner. An analysis is conducted on the characteristics of force flow and its manifestations in both natural and engineering contexts [34]. This method takes into account both the mechanical constraints (such as boundary conditions, load arrangement, and volume %) and the geometric constraints (including the total number of pieces, minimal overhang, maximum length, and minimum thickness). It then generates a 2D design that complies with these limitations [35]. Therefore, it amalgamates the benefits of mechanical (CAE) design and geometrical design. Conversely, the limitations on geometric DfAM methods, as well as the range of applications and materials, are intricate, lacking a standardized framework, and lacking uniformity [36]. Some concepts lack a precise mathematical description, while others have a clear mathematical explanation but are proprietary and not accessible to the public [37, 38].

Vaneker *et al* (2020) presents a framework for DfAM methods and tools, subdivided into three distinct stages of product development: AM process selection, product redesign for functionality enhancement, and product optimization for the AM process chosen. The research illustrate the applicability of the design framework using examples from both research and industry. However, DfAM is a field that is rapidly evolving, and many challenges still remain such as its suitabily and product redesign for AM [23].

Wiberg *et al* (2019) has reviewed over 1,500 publications in the area of design for AM, design automation for AM, and optimization and AM. The publications have been filtered and review based on over 100 papers has been compiled. Based on the review, a new detailed DfAM process has been proposed together with a mapping of available design support in the form of methods, design rules, guidelines and software tools [39].

2. Methodology

In this study, the framework depicted in figure 1 will be utilized in order to further develop the case study. The design application aims to create a platform that will work as a knowledge extraction tool for function integration and structure simplification specifically for FDM printing process. The platform creates the interface for communication between user and the design requirements. All the case studies presented in this paper were proposed to be printed with FDM 3D printer. FDM employs a layer-by-layer deposition approach in which molten materials such as polymers, composites, metals, or ceramics are extruded through a nozzle with a small aperture and merge with the material on the preceding layer. The pattern for each layer is determined by mechanical manipulation of the nozzle's x-y location and can be unique or arbitrary for each deposited layer.

In the design process flow, the user has to indicate the product function integration and structure simplification with a clear grasp of the problem. As a result, the most appropriate AM design knowledge to ensemble specific particular design needs based on input characteristics such as material type, form, machining behavior, process method, and the FDM process capabilities such as holes, tolerance, connecting and moving components, support and overhangs.

Design knowledge refers to the designer's understanding of the AM design features, process selection, and design concerns. It necessitates knowledge for evaluating arguments and making decisions that impact processing complexity, assembly difficulty, the number of components, accuracy, expense, weight, and time consumption.

The key enabling technologies defines some of the options for part design optimization to successfully construct a design process model for functional integration and structure simplification.

Through the presentation of the case study and the methodology that was utilized from the AM categories, this part provides an explanation of the methodology that was utilized in this research. This framework will be

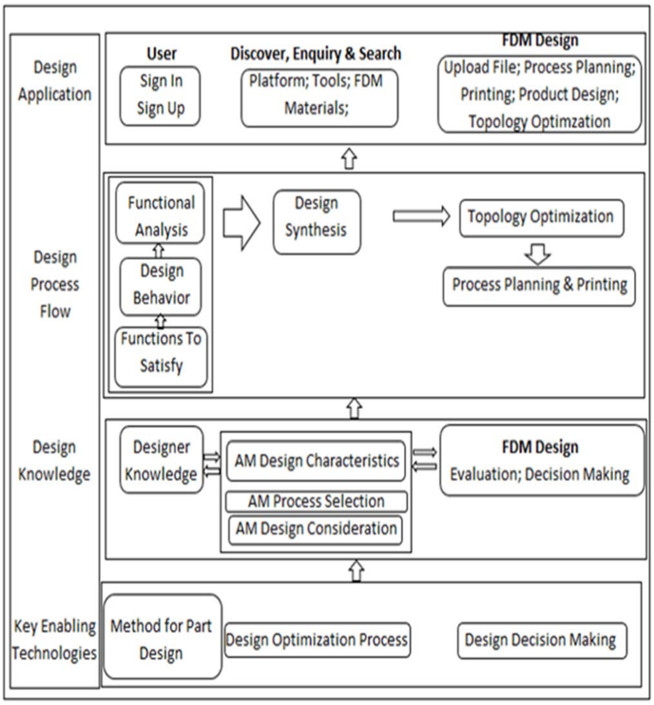

Figure 1. Framework used for case study.

able to present the analysis that was performed prior to the final product being completed. There will be a number of case studies that will be representative of a few of the AM categories that enable the goods to be improved or changed without causing a significant amount of material waste. This will allow for the parts to be easily replaced.

The goal of this research is to examine the design methods for embedded components that are to be used in FDM additive manufacturing systems. Case studies will be investigated and analyzed in order to develop an effective framework for embedded components. This will be done in order to design the framework. The integrated embedded design that is built together with the usage of FDM and the effectiveness of decreasing waste material by exchanging the parts that include the embedded design are both included in the case study.

A total of three case studies was conducted which involve three separate products that could be manufactured through the process of FDM. Where the first case study focuses on an electric shaver, the second case study focuses on a remote controller and the last case study focuses on a game console which in this case, a Nintendo Switch. This project made use of the framework to cut down on the number of components and assemblies, which ultimately led to an improvement in product design. For the purpose of addressing embedded product design difficulties, a four-layered design framework was developed by utilizing Design Process Flow, Design Knowledge, Key Enabling Technologies, and Design Application.

It is good practice to apply the 45° rule when designing parts for FDM: features with angles less than 45° must be supported to ensure a part won't break during the printing process. To ensure a successful print, one rule of thumb is to design walls twice the thickness of the nozzle diameter, with a minimum of 1.5–2 mm thickness. FDM process typically produces undersized holes. Therefore, it is best practice to design oversized holes. It often makes sense to split complex 3D model into several pieces, printed separately and then assembled together later. This will speed up the printing process while saving material for the support structures. Material in FDM is heated during the printing process, temperature changes that occur can lead to deformations of the printed part. By adding a chamfer along the bottom edge of a part, thermal stresses can be distributed more evenly, mitigating warping and shrinkage.

2.1. First case study (electric shaver)

An electric shaver, alternatively referred to as a dry razor, electric razor, or simply shaver, is a razor equipped with an electrically powered blade that either rotates or oscillates. Electric razors typically do not necessitate the application of shaving lotion, soap, or water. A battery-powered or mains-powered miniature DC motor may be utilized to operate the razor. Numerous modern models operate on rechargeable batteries. As illustrated in figure 2, an electromechanical oscillator fuelled by an AC-energized solenoid may also be utilized. Certain early

Figure 2. Phillips electric shaver.

Figure 3. Interchanging back cover.

Figure 4. Interchanging back cover.

mechanical razors lacked electric motors and required manual operation, such as the rotation of a flywheel by drawing a string.

The Philips electric shaver was chosen in conjunction with an embedded circuit design that permits simple replacement without the need to purchase an entirely new set. This can contribute to the reduction of waste generated by the item through the recycling of the component alongside the new replacement component. This design behavior permits incremental changes, allowing the user to continue utilizing the product without divulging it. Each of the parts can be disassembled, as shown in figure 3, with friendly user guidance that can allow the user to interchange any parts, as shown in figure 4.

Figure 5. Interchanging back cover.

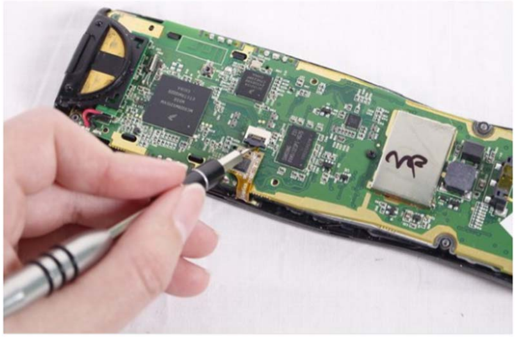

Figure 6. Remote control with embedded design to change the main board.

Figure 7. Removing embedded parts in remote control.

2.2. Second case study (remote control)

As illustrated in figure 5, a Logitech Harmony 900 (M/N) universal remote (M-R0001). Once the battery cover is extracted from the battery chamber, the model number becomes apparent. Its purpose is to manage the components of your entertainment system, including your television, cable box, DVD player, and game console. It was introduced in 2009 and is no longer offered.

In order to provide the user with enhanced topology optimization, the design process flow has been incorporated with the functions depicted in figure 5, which illustrates superb design behavior. In these critical enabling technologies, the method of part design utilizing FDM permits the user to modify individual components without regard to any components in the remote control, particularly the 'analogue,' which is prone to deterioration once the component's lifecycle has expired. As illustrated in figure 6, as a consequence, the design application equips the user with specialized tools for disassembling the remote control, thereby preventing the need to discard the entire set in the event of single-part defects. The users can easily replace the embed parts as shown in figure 6, with a plug-and-play method instead of considering the whole set instead of considering the whole set to be malfunctioning. The users are also allowed to replace the embedded design parts quickly, as shown in figure 7, with proper tools to prevent additional pressurization on the flex cable made from multiple soft materials.

Figure 8. Nintendo switch.

Figure 9. Left Joy-Con sensor rail embedded design replacement in the main module.

2.3. Third case study (gaming console)

Nintendo introduced the Nintendo Switch, a hybrid video game console, in the majority of regions worldwide in 2017. A hybrid console, the tablet-like console can be tethered and utilized as either a home console or a portable device. To facilitate portable gaming, the console's wireless Joy-Con controllers, featuring conventional buttons and directional analog sticks for user input, motion detection, and tactile feedback, can be affixed to either side. Additionally, they can be affixed to a grasp device to resemble traditional home console gamepads, or they can function autonomously in the hand like the Wii Remote and Nunchuk to enable local multiplayer modes (fgure 8).

The Nintendo Switch features an incorporated design that incorporates the most recent design architecture. Improving design knowledge and facilitating technologies with diverse types of design are crucial for optimising and streamlining topology. Due to its modular construction and adaptability, this design permits users to interchange components piece by piece without interruption. As an illustration, a fully assembled Nintendo Switch comprises a central module and two distinct Joy-Cons (Left and Right), which are integrated to form a unified aesthetic. Users enable rapid component replacement without causing damage to the entire module (figure 9).

Nintendo Switch Joy Con is built with FDM using ABS polymerization material and integrated embedded design to form a robust, long-lasting joy con. It is allowed to change every single part in the joy-con, including the shell (Casing), to continue using it.

3. Results and discussion

3.1. First DfAM case study

According to the framework in figure 10, enhancements will be made to the electric shaver to improve its performance in terms of hair trimming, increase its battery capacity for longer use, and make it easier to grip.

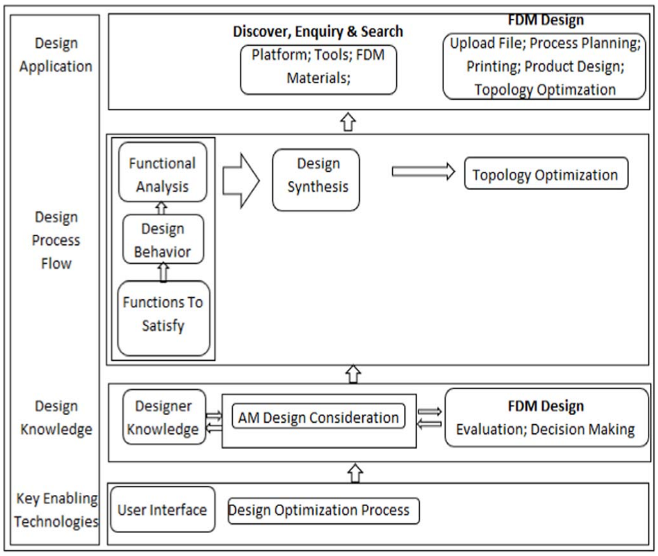

Figure 10. Embedded framework for shaver enhancement.

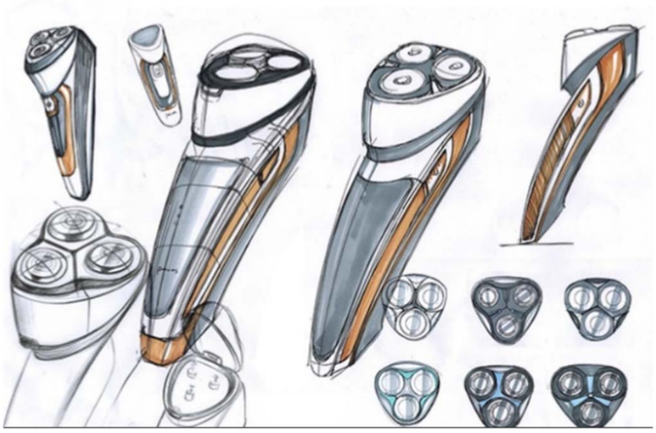

Figure 11. Conceptual design of shaver.

The benefits of these enhancements include the ability to easily switch out rotary blades, a protective casing for the blades, a housing for the shaver, and a rechargeable battery. The shaver is equipped with an integrated Lithium Polymer battery, a generally available kind on the market. This design ensures that the user can use the shaver continuously without the need for disposal.

Presented in figure 11 is the conceptual sketch of the electric shaver, which incorporates improvements to its benefits through the utilization of the FDM method. The structure is constructed using polycarbonate, a robust and heat-resistant material that also possesses flame-retardant properties, ensuring durability. This design incorporates a blade interchangeability feature, allowing for the replacement of individual blades without the need to discard the entire shaver. Furthermore, embedded system design will have various design metrics that are required as shown in table 1 below.

The disadvantages of the electronic shaver are that the shaver is too bulky which will be difficult to keep, and no indicator of the blade life span whereby the indicator is only for battery indication.

According to table 2, the framework is constructed utilizing polycarbonate as opposed to plastic material for the case. This is because of the inherent hardness that may be achieved with polycarbonate. The design has replaceable blades, which effectively reduces product wastage by allowing the blade to be used multiple times. The system incorporates an artificial intelligence that provides a blade lifespan indication, alerting the user to the remaining usage capacity of the blade. The design's thickness provides a comfortable shaving experience,

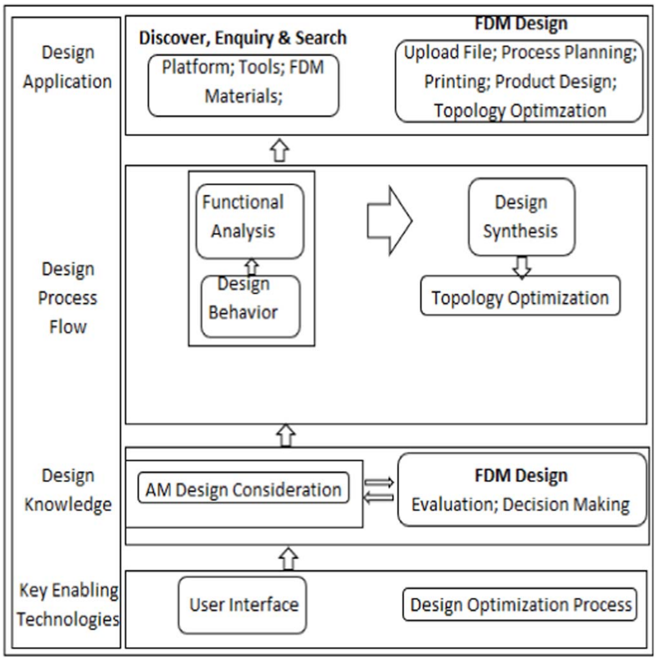

Figure 12. Embedded framework for remote control enhancement.

Table 1. Design metrics on shaver improvement.

Design metrics / design parameters	Functionality
Power Dissipation	Always kept at a low level
Performance	High
Process Deadlines	The process/task must be finished within a certain amount of time.
Manufacturing Cost	Maintained at the same cost
Engineering Cost	Maintained at the same cost
Size	Memory RAM / ROM / Flash Memory/Physical Memory is used to describe size.
Prototype	It is the entire amount of time spent designing and testing a system.
Safety	System security, such as phone locking, and user security, such as engine breakdown safety measures, should be implemented.
Maintenance	To avoid system failure, proper system maintenance must be performed.
Time To Market	It is the time it takes for a created product or system to be released to the market.

Table 2. Validation framework for electric shaver.

Electric shaver	Current electric shavers in the market	Framework design improvement
Case	Plastic material	Polycarbonate
Design	Fix	Blade interchangeable
System	Only the battery percentage shown	Battery percentage shown and blade lifespan indication
Thickness	Very bulky	Handheld design
Charging	External charging station	Using a common cable for charging

reducing discomfort in the hand. Additionally, it is equipped with a charging cord that is compatible with standard outlets, allowing the user to conveniently recharge the shaver anywhere, anytime.

3.2. Second DfAM case study

According to figure 12, the remote control will be improved using an embedded framework in order to boost its performance. This encompasses the versatile functionality of the remote control, which allows it to establish connections with a wide range of communication devices, including but not limited to televisions, radios, computers, and others. Regarding the remote control, the user interfaces play a crucial role in improving its functionality for multitasking with communication devices.

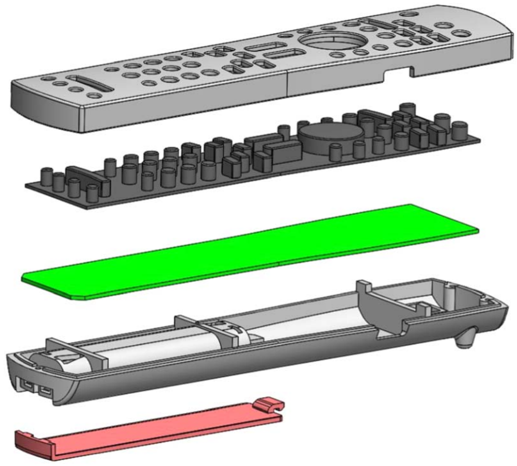

Figure 13. Drawing for remote control.

Table 3. Design metrics on remote control improvement.

Design metrics / design parameters	Functionality
Power Dissipation	Maintain at the same level
Performance	High
Process Deadlines	The process/task must be finished within a certain amount of time.
Manufacturing Cost	Maintained at the same cost
Engineering Cost	Maintained at the same cost
Size	Compact size with less complexity
Prototype	It is the entire amount of time spent designing and testing a system.
Safety	System security to avoid communication breakdown.
Maintenance	To avoid system failure.
Time To Market	It is the time it takes for a created product or system to be released to the market.

Table 4. Validation framework for remote control.

Remote control	Current remote control in the market	Framework design improvement
Case	Plastic	Thermoplastic polyurethane
Design	Standard design	Additional keyboard interface
Power	No indication of the battery	Indicator included for battery
Size	Long and bulky	Compact
Usage	Inconvenient during screen button selection	Convenience with the keyboard intact

The casing for the remote control will be fabricated using FDM material. The material employed is thermoplastic polyurethane. This material is utilized for constructing remote controls due to its superior flexibility, excellent abrasion resistance, wear resistance, and high strength. This remote control cover can be easily swapped with other designs that are compatible with remote controls of the same size. According to figure 13, the incorporation of a keyboard into the remote control enables the user to connect to a communication device and conveniently search for keywords by entering on the keyboard, rather than selecting letters from the screen. Furthermore, embedded system design have various design metrics that are required as shown in table 3.

The remote control has several drawbacks. Firstly, its bulky size makes it challenging to keep in a convenient location. Additionally, the presence of a keyboard on the bottom of the remote increases the possibility of accidental button presses, particularly if it is placed within reach of children. This remote control lacks water resistance, which poses a risk when viewing TV during a tea break. This also excludes the battery life indicator, which notifies the user when the battery is running low. Furthermore, validation has been conducted in accordance with table 4.

Table 4 displays the enhancements made to the remote control with the aid of the framework design. The case employs Thermoplastic polyurethane, which exhibits superior abrasion resistance in comparison to the

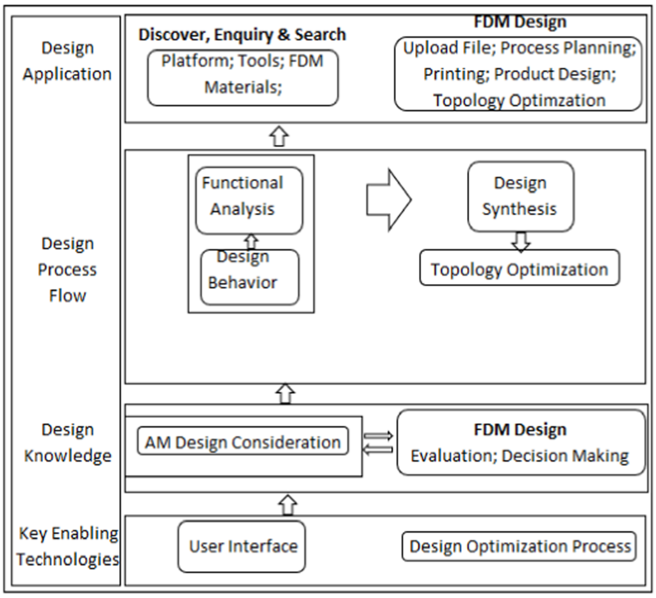

Figure 14. Embedded framework for nintendo switch enhancement.

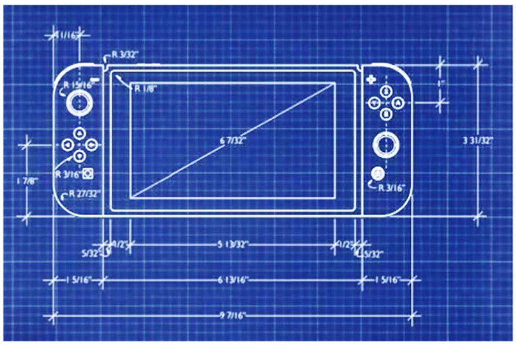

Figure 15. Nintendo switch design stage.

current plastic material. The design features a sophisticated built-in keyboard that enables the user to effortlessly type using the Qwerty keyboard layout. The power usage is readily visible from the indicator, despite the keyboard's tiny size in contrast to the longer and bulkier current model.

3.3. Third DfAM case study

The Nintendo Switch, which was the initial release of a console with integrated hybrid hardware, provided a wide range of gaming experiences. Nevertheless, the need for adaptability in the Nintendo Switch to accommodate various hardware setups exposes certain vulnerabilities of the system. This component is constructed using the FDM technique and is made from ABS polymerization material. ABS polymerization offers superior rigidity and durability, as well as the capacity to tolerate high temperatures. It is available in a range of colors and may be combined with other materials. Additionally, ABS polymerization is resistant to abrasion. Each iteration of the Nintendo Switch is constructed using modular components, allowing users to avoid incurring additional expenses by purchasing a completely new set (figure 14).

Based on the design depicted in figure 15, it is imperative that the design is appropriate for a handheld posture, ensuring that the user does not experience any numbness while holding it for a minimum of two to three hours. Moreover, this design is essential for ensuring the user's comfort while holding the Nintendo Switch for extended periods of time, in order to meet the basic requirements of a handheld device. Furthermore, this component requires meticulous finishing following the FDM process. Table 5 below displays a selection of the functional requirements that are considered throughout the design phase.

Table 5. Design metrics on nintendo switch improvement.

Design metrics / design parameters	Functionality
Power Dissipation	Always kept at a low level
Performance	High
Process Deadlines	The process/task must be finished within a certain amount of time.
Manufacturing Cost	Maintained at the same cost
Engineering Cost	Maintained at the same cost
Size	Size must remain the same according to the old model.
Prototype	It is the entire amount of time spent designing and testing a system.
Safety	System security, such as phone locking, and user security, such as power shutdown safety measures, should be implemented.
Maintenance	To avoid system failure, software upgrades must developed from time to time.
Time To Market	It is the time it takes for a created product or system to be released to the market.

Table 6. Validations on nintendo switch.

Nintendo switch	Current design in the market	Framework design improvement
Performance	Standard frequency for screen refresh	Higher frequency for high-quality screen refresh
Power	Lower battery capacity	Bigger battery capacity
Screen	Standard resolution	Higher resolution
Case	Plastic	ABS polymerization
Hardware	Fix	Interchangeable Parts

The drawbacks of the Nintendo Switch are its limited battery life and the standard screen refresh rate of 60 Hertz. Furthermore, it is important to note that the screen of the Nintendo Switch is capable of providing a maximum resolution of 1920 $\times$1080, even when connected to a television via a dock. However, some users may not find the experience enjoyable due to the fact that the market is moving towards higher-quality HD images. Furthermore, this also contributes to the exorbitant price, rendering many users unable to make any purchases, particularly for the remote control that is specifically designed for usage in docking mode. The Nintendo Switch does not have water resistance, which poses a risk when using it in docking mode during a tea break. Furthermore, the Nintendo Switch has undergone validation with the assistance of the framework, as depicted in table 6 below:

According to table 6, the framework indicates that the Nintendo Switch offers greater benefits, particularly in terms of performance, which is the aspect that users prioritize the most during their games. Hence, the framework enhances gameplay by augmenting the screen refresh rate, thereby ensuring seamless performance throughout program loading. The power is being augmented with more capacity to extend the Nintendo Switch's battery life beyond the usual duration of games. The case is constructed with abrasion resistance, enabling it to withstand user handling. Additionally, it features interchangeable parts, allowing the user to continue using the module without the need for disposal in the event of damage.

Panesar *et al* (2015) proposed a framework for the design of AM multi material parts with embedded functional systems (e.g., structure with electronic/electrical components and associated conductive paths). Two major strands of this suggested architecture are placement and routing strategies, which are techniques for creating 3D printed circuit volumes by using the true-3D design freedoms of multifunctional AM. Example test cases are provided to demonstrate the applicability and effectiveness of the proposed methodologies [40]. Yao *et al* (2018) presented a framework for creating multi-material parts with AM techniques. The suggested framework consists of four interacting modules: design requirement identification, main material selection, AM process selection, material composition, and part geometry determination. The proposed framework is used in a case study involving the conceptual design of a multi-material battery pack cooling plate. The suggested framework incorporates AM rules and standards, as well as AM processes' capabilities and constraints, which are stored in databases [41]. However, the framework proposed in this paper was utilized to reduce components and assemblies to improve product design. To ensure environmental sustainability, the framework emphasizes materials used to make recyclable items. Design Process Flow, Design Knowledge, Key Enabling Technologies, and Design Application were used to create a four-layered design framework to tackle embedded product design challenges specifically for the FDM system.

4. Conclusion

The main objective of this research was to utilize the FDM method for developing diverse design strategies aimed at 3D printing embedded components. FDM offers numerous benefits to designers and manufacturers in the creation of things. The FDM technique offers several advantages, including fewer material issues, for producing items. This also enables greater freedom in designing applications based on a framework. On the other hand, the proposed framework would assist in mitigating the time limitation that many designers and makers encounter during the earliest stages of product creation.

The second objective involves analyzing three types of case studies to propose a paradigm for embedded components design techniques for FDM systems. The embedded framework serves the objective of aiding developers in customizing and interacting with hardware and software characteristics. The proposal framework is categorized into numerous forms, enabling the maker or designer to have a perspective on product design. Furthermore, this framework enables the creator to gain a more comprehensive comprehension of product development within a specified time range.

Lastly, three types of case studies are employed to compare the materials utilized in the FDM process and assess the efficacy of the suggested framework for the products. The case studies focused on the most prevalent usage and purchasing patterns in the market, along with further analysis of the benefits and drawbacks of utilizing FDM materials within the proposed framework.

Although the proposed framework to aid the design strategy typically for the FDM process, it is acknowledged that actual fabrication may encounter unforeseen challenges such as cost, structural property variations, process optimization requirements, post-processing needs, and quality assurance considerations. Further analysis to compare the printed samples quality and the framework proposed is recommended.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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