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IMPLEMENTATION STUDY OF AN INTELLIGENT GREENHOUSE BOX FOR STORING 3D CAD/CAM PRINTING FILAMENTS

ESTUDO DE IMPLEMENTAÇÃO DE UMA CAIXA ESTUFA INTELIGENTE PARA ARMAZENAR FILAMENTOS DE IMPRESSÃO 3D CAD/CAM

ESTUDIO DE IMPLANTACIÓN DE UNA CAJA DE INVERNADERO INTELIGENTE PARA ALMACENAR FILAMENTOS DE IMPRESIÓN 3D CAD/CAM

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ABSTRACT

The storage of 3D printing filaments in unsuitable environments can significantly compromise the quality of the prints, due to moisture absorption and thermal degradation of the material. Filaments such as PLA, for example, become brittle and unstable when exposed to humidity for long periods, resulting in extruder clogging and unevenly finished surfaces. Considering this scenario, it is important to develop solutions that guarantee the preservation of filament properties over time. Developing an intelligent oven that keeps the filaments at a controlled temperature and humidity, continuously, with real-time monitoring, is the central objective of this research. The proposal aims to increase the useful life of the filaments, preserve their mechanical integrity and guarantee print quality.
The methodology adopted included technical research into components and control systems, the development of a CAD-CAM model of the oven and the construction of an operating flowchart based on temperature and humidity sensors, active dehumidification modules (Peltier and silica gel), heating via electrical resistors and control with ESP32. Preliminary results have shown that inadequate storage of PLA compromises its performance, while controlled storage allows for prints of higher quality and stability. The design of the oven was also adjusted to accommodate up to 20 kg of filament with a sealed and modular structure. The proposed smart oven is a viable and effective alternative for minimizing material losses, promoting sustainability in the use of filament and ensuring more efficient printing.

Keywords: 3D printing. Filaments. Smart greenhouse. Controlled storage. Humidity.

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RESUMO
O armazenamento de filamentos de impressão 3D em ambientes inadequados pode comprometer significativamente a qualidade das impressões, devido à absorção de umidade e degradação térmica do material. Filamentos como PLA, por exemplo, tornam-se quebradiços e instáveis quando expostos à umidade por longos períodos, resultando em entupimentos da extrusora e superfícies com acabamento irregular. Considerando esse cenário, torna importante o desenvolvimento de soluções que garantam a preservação das propriedades dos filamentos ao longo do tempo. Desenvolver uma estufa inteligente que mantenha os filamentos em temperatura e umidade controladas, de forma contínua, com monitoramento em tempo real, é o objetivo central desta pesquisa. A proposta visa aumentar a vida útil dos filamentos, preservar sua integridade mecânica e garantir qualidade nas impressões.
A metodologia adotada incluiu a pesquisa técnica de componentes e sistemas de controle, o desenvolvimento de um modelo CAD-CAM da estufa e a construção de um fluxograma de funcionamento baseado em sensores de temperatura e umidade, módulos de desumidificação ativa (Peltier e sílica gel), aquecimento via resistências elétricas e controle com ESP32.
Os resultados preliminares demonstraram que o armazenamento inadequado de PLA compromete sua performance, enquanto o armazenamento controlado permite impressões de maior qualidade e estabilidade. O projeto da estufa também foi ajustado para acomodar até 20 kg de filamento com estrutura vedada e modular. A estufa inteligente proposta é uma alternativa viável e eficaz para minimizar perdas de material, promover a sustentabilidade no uso de filamentos e garantir impressões mais eficientes.

Palavras-chave: Impressão 3D. Filamentos. Estufa inteligente. Armazenamento controlado. Umidade.

RESUMEN
Almacenar los filamentos de impresión 3D en entornos inadecuados puede comprometer considerablemente la calidad de las impresiones, debido a la absorción de humedad y la degradación térmica del material. Filamentos como el PLA, por ejemplo, se vuelven quebradizos e inestables cuando se exponen a la humedad durante largos periodos, lo que provoca atascos en el extrusor y superficies con acabados desiguales. Teniendo en cuenta este escenario, es importante desarrollar soluciones que garanticen la conservación de las propiedades del filamento a lo largo del tiempo. Desarrollar un horno inteligente que mantenga los filamentos a una temperatura y humedad controladas, de forma continua, con monitorización en tiempo real, es el objetivo central de esta investigación. La propuesta pretende aumentar la vida útil de los filamentos, preservar su integridad mecánica y garantizar la calidad de impresión.
La metodología adoptada incluyó la investigación técnica de componentes y sistemas de control, el desarrollo de un modelo CAD-CAM del horno y la construcción de un diagrama de flujo operativo basado en sensores de temperatura y humedad, módulos de deshumidificación activa (Peltier y gel de sílice), calentamiento a través de resistencias eléctricas y control con ESP32.
Los resultados preliminares han demostrado que un almacenamiento inadecuado del PLA pone en peligro su rendimiento, mientras que un almacenamiento controlado permite obtener impresiones de mayor calidad y estabilidad. El diseño del horno también se ajustó para acomodar hasta 20 kg de filamento con una estructura sellada y modular. El horno inteligente propuesto es una alternativa viable y eficaz para minimizar las pérdidas de material, promover la sostenibilidad en el uso del filamento y garantizar una impresión más eficiente.

Palabras clave: Impresión 3D. Filamentos. Invernadero inteligente. Almacenamiento controlado. Humedad.

INTRODUCTION

3D printing has been consolidated as a prototyping and custom production tool in recent years, being used in sectors such as engineering, dentistry, design, and education. The process is based on the successive deposition of layers of molten thermoplastic material, such as PLA (polylactic acid) and ABS (acrylonitrile butadiene styrene), to form three-dimensional objects. However, one of the challenges faced by users is the proper storage of the filaments used in this process.

As highlighted by Carvalho (2019), the moisture absorbed by the PLA filament can significantly compromise its mechanical properties and generate dimensional variations, affecting the quality of 3D printing and making it essential to maintain the filament in a controlled environment. The absorption of moisture by thermoplastic filaments alters their melting point, promotes the formation of internal bubbles during extrusion, generates inconsistencies in the material flow, and leads to the formation of parts with poor interlayer adhesion, rough surfaces, and structural failures. This degradation can also result in extruder nozzle clogging, adhesion failures to the print bed, and process interruption, representing material and time losses.

PLA (polylactic acid) is a biodegradable thermoplastic polymer derived from renewable sources such as corn starch or sugarcane. Its chemical structure contains ester groups, which are highly susceptible to hydrolysis — a chemical reaction in which water breaks molecular bonds. This characteristic makes PLA more vulnerable to degradation when exposed to air humidity, even at moderate levels. In addition, PLA has a low glass transition temperature (about 60 °C), which causes it to lose rigidity quickly in slightly heated environments, making it even easier to absorb water.

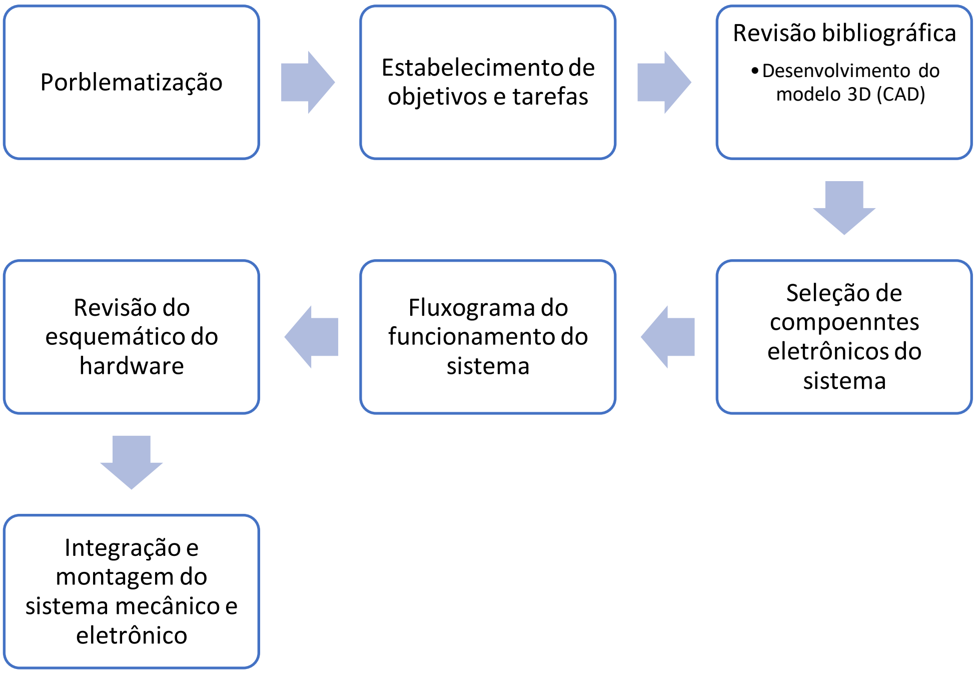
Faced with this problem, this project aims to develop a smart greenhouse for the storage of 3D printing filaments, capable of keeping temperature and humidity within ideal ranges through automation and real-time monitoring. The proposed system seeks to preserve the integrity of the filaments over time, extending their useful life and ensuring quality in the prints.

TASKS DEVELOPED SO FAR

- Comparative tests between filaments stored in different environmental conditions;
- CAD-CAM modeling of the greenhouse;
- Definition of functional and structural requirements of the system;
- Development of the on-board control flowchart;
- Study and specification of sensors, actuators and microcontroller.

METHODOLOGY

The methodology adopted in this work is characterized as applied experimental research, aimed at the development of a functional prototype of an intelligent greenhouse for the storage of 3D printing filaments. The project was conducted in structured stages, combining technical literature review, three-dimensional modeling (CAD), selection of electronic components, operation simulations and practical storage tests. Initially, an analysis of the thermal and hygroscopic properties of the main filaments used in 3D printing was carried out, with emphasis on PLA, in order to understand the effects of humidity on their physical integrity and performance during extrusion. Next, the functional requirements of the greenhouse were defined: maintaining relative humidity below 10%, stable temperature between 35 °C and 45 °C, automatic control by microcontroller and the ability to store up to 20 kg of filament in coils.



The CAD-CAM design of the greenhouse was developed considering a modular structure of approximately 100x100x100 cm, manufacturable in aluminum or stainless steel, with adjustable shelves and hermetic sealing by silicone rubber. To ensure internal thermal insulation and avoid heat dissipation, the use of lining with glass wool or rock wool was specified.

For environmental monitoring, temperature and humidity sensors (such as DHT22 or SHT30) were selected, and control was delegated to an ESP32 microcontroller, responsible for reading the sensors, activating the heating system (low-power ceramic resistors).

A logical flowchart of operation was prepared to guide the structure of embedded firmware. The system operates in continuous cycles, reading the sensors and activating the actuators according to the pre-configured tolerance ranges. Safety routines were provided, such as automatic shutdown in case of sensor failure or overheating, as well as visual status indicators.

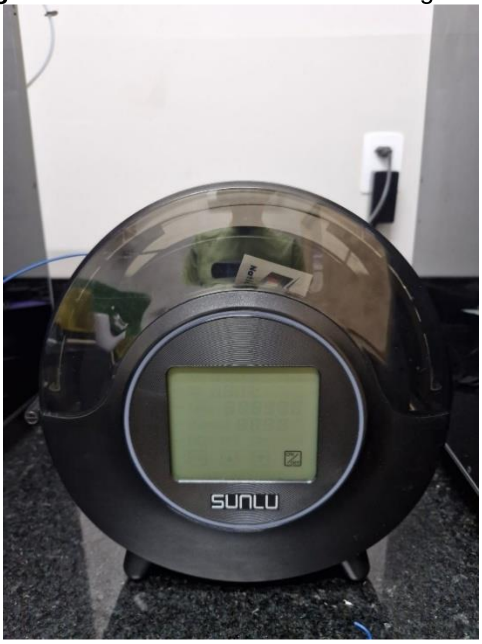
RESULTS

The experimental stage focused on the evaluation of the behavior of PLA filaments stored under different conditions, with the aim of quantifying the effects of humidity and validating the need for a controlled environment such as the one proposed in the smart greenhouse box. In the tests carried out, the **Premium Black PLA filament** stored in an open environment showed marked fragility, with breaks during printing, clogging of the extruder nozzle and low adhesion to the printing table. These problems compromised the quality of the parts and indicated the structural degradation of the material due to moisture absorption.

On the other hand, sealed PLA, without direct exposure to ambient humidity, achieved superior performance. Although it still had a small fragility, the material did not cause clogs or extrusion failures, with stable flow and prints with an acceptable visual finish. These data corroborate previous studies (CARVALHO, 2019; KAMIO and ONDA, 2022) that point to the hygroscopic behavior of PLA as a critical factor for its thermal and mechanical stability.

In a third condition, the impact of preheating the open PLA in a conventional mini-greenhouse (eSun model) for 2 hours before printing was evaluated. The result was positive: the filament exhibited consistent flow, absence of clogs and parts with excellent surface finish, evidencing the effectiveness of thermal control even in a punctual way.

Figure 1 – Greenhouse used for storage tests



Author: authors, 2025.

In addition to the filament tests, the initial design of the greenhouse was completed, including CAD/CAM modeling and definition of the technical requirements for the automated control by ESP32, DHT22 sensors and active dehumidification. The printers used were Creality CR10s and K1 MAX models, ensuring compatibility with filaments for professional use.

Figure 2 – Printers used for the print tests

Author: authors, 2025.

These results reinforce the feasibility of the proposal and its practical importance to ensure longevity of filaments, reduce waste and significantly improve the quality of 3D printing.

Figure 3 - CAD/CAM design of the filament greenhouse.

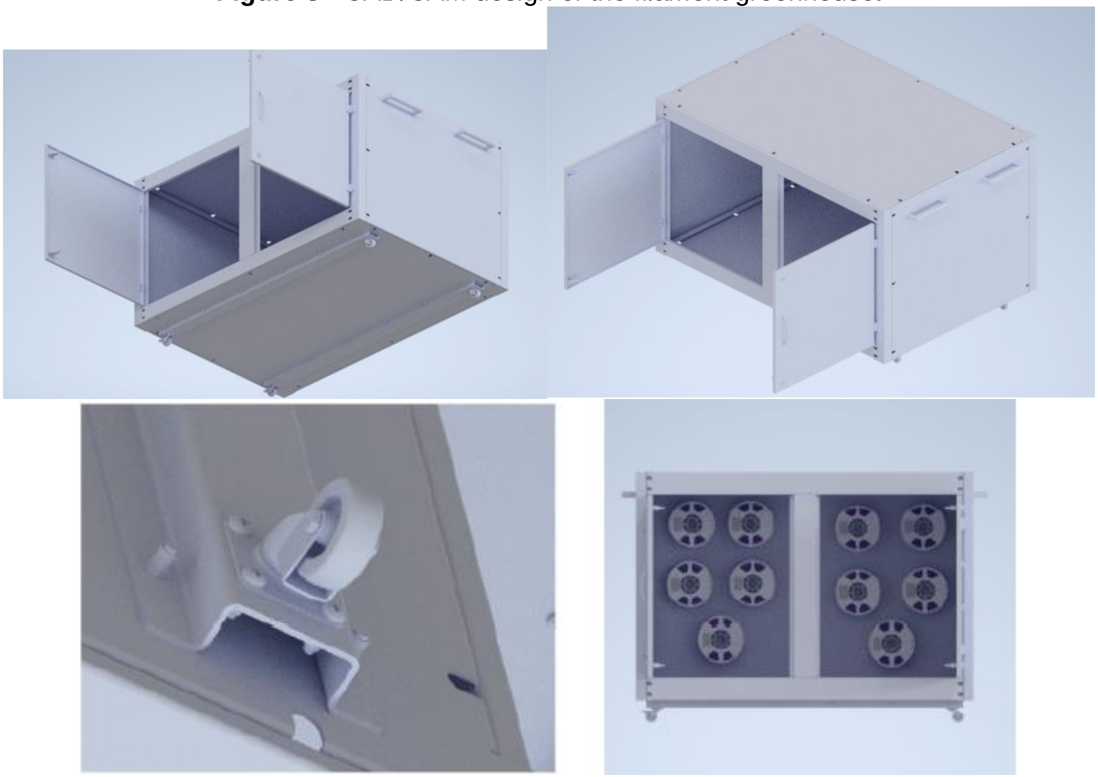


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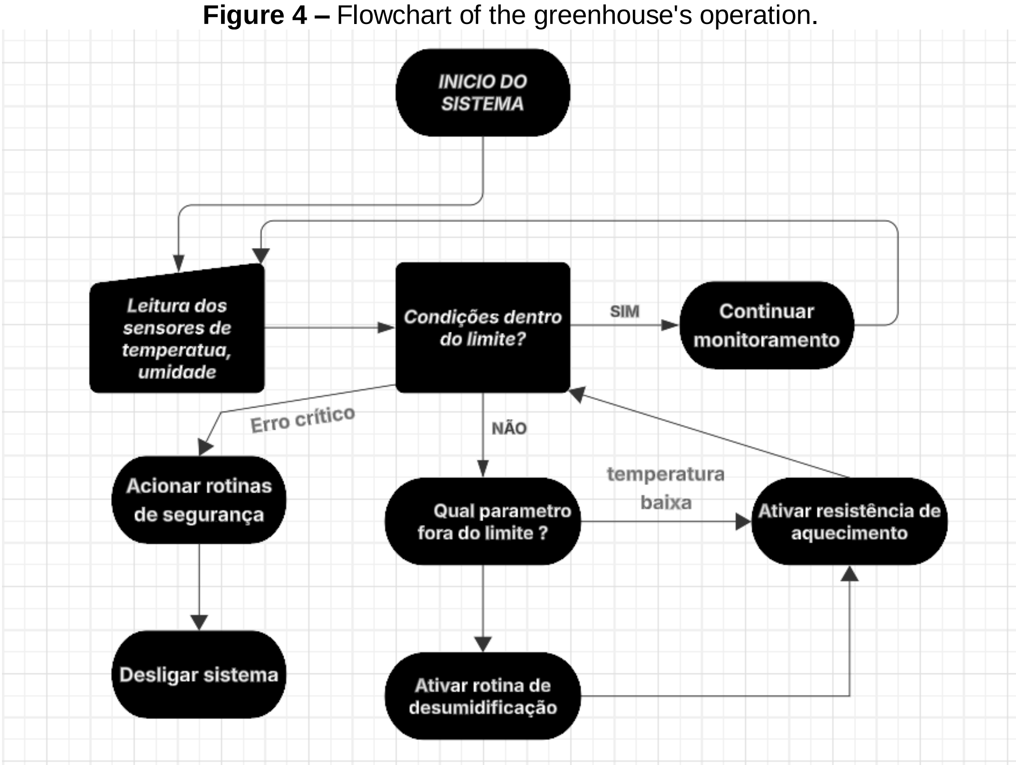
Figure 4 – Flowchart of the greenhouse's operation.



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DISCUSSION

The results obtained during the practical tests confirm the influence of moisture on the performance of thermoplastic filaments, especially PLA. The weakened behavior, clogging and poor adhesion observed in filaments stored in an open environment are compatible with the technical literature, which characterizes PLA as a highly hygroscopic and thermally unstable material (CARVALHO, 2019; KAMIO and ONDA, 2022). These effects directly compromise print quality and increase scrap and rework rates, especially in applications that demand dimensional accuracy and adequate surface finish.

While sealed storage partially mitigates the effects of moisture, it does not completely eliminate the risk of degradation, especially in environments. Pre-press heating, on the other hand, proved to be an effective solution, but punctual, which does not solve the problem continuously or preventively. This reinforces the need for an active and automated storage solution, such as the proposed smart greenhouse.

The project developed presents a relevant differential by proposing an automated environmental control system, with real-time monitoring and adaptive action according to the internal conditions of the box. The use of precise sensors, microcontroller, and thermal insulation with glass or rock wool gives the prototype robustness, energy efficiency, and scalability.

In this way, the data obtained not only validate the concept of the smart greenhouse, but also indicate that its use can represent a practical and economical solution to extend the useful life of filaments and raise the quality standard of prints.

CONCLUSION

This work aimed to develop an intelligent solution for the storage of 3D printing filaments, seeking to mitigate the negative effects of inadequate humidity and temperature on materials such as PLA, sensitive to these variables. Through the elaboration of a structured CAD/CAM project, the selection of components and the construction of a microcontroller-based control system, it was possible to propose a functional greenhouse, technically feasible and of direct application in academic and professional environments.

Practical tests have shown that improper storage compromises the performance of the filaments, resulting in extrusion failures, poor adhesion and loss of mechanical integrity of the printed parts. On the other hand, the use of a greenhouse with thermal control — even in simple commercial solutions — proved a substantial improvement in the quality of the prints, validating the proposal of a more robust, automated and continuous structure.

The smart greenhouse developed stands out for integrating real-time temperature and humidity control, thermal insulation with materials such as glass wool or rock, and a modular structure capable of storing up to 20 kg of filaments. This approach promotes not only the reuse of sensitive materials, but also reduces waste, improves printing efficiency, and extends the useful life of inputs.

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