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Ergonomic Optimization of a 3D Printing Workstation Through the Reorganization of Raw Material Storage

Gina-Mihaela SICOE, Daniel-Constantin ANGHEL*
National University of Science and Technology POLITEHNICA Bucharest, Pitesti University Centre

*Corresponding author e-mail: dc.anghel@upb.ro

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Abstract. This paper aims to analyze the ergonomic design of a workstation dedicated to the use of a 3D printer, focusing primarily on the storage and organization of raw materials used in additive manufacturing. The study is based on a real-world scenario in which the materials were initially placed randomly on shelves, without consideration for their usage frequency or weight. This disorganized arrangement led to repeated or awkward operator movements, such as reaching above shoulder level or excessive bending, which may cause discomfort or musculoskeletal disorders over time. Furthermore, this inefficient setup negatively affected operator performance.
To improve the ergonomics of the workstation, we proposed a reorganization of the materials based on ergonomic principles, considering both the weight and usage frequency of the items. Heavier and less frequently used materials were relocated to the lower shelves, while lighter, frequently accessed items were positioned within the operator's comfort zone—around waist to chest height. The goal was to reduce physical strain, enhance operational efficiency, and prevent occupational health risks.
The study also includes an evaluation of the redesigned workstation using the RULA (Rapid Upper Limb Assessment) method, in order to quantify the biomechanical load in both the initial and improved configurations.
Keywords: RULA, reorganization, workstation design

INTRODUCTION

In today's industrial context, improving workstation design is a key concern for increasing operational efficiency and minimizing health-related risks for employees. Ergonomics plays a vital role in the design and organization of workspaces, aiming to adapt them to the physiological and psychological needs of operators.
Recent studies emphasize the importance of ergonomic organization of storage spaces, especially in industries where frequent material handling is involved. For instance, research on ergonomic layout in garment manufacturing facilities has demonstrated that a properly designed workstation can significantly reduce discomfort and the risk of musculoskeletal disorders among operators [1], [2], [3].
In the field of additive manufacturing, the use of 3D printers has grown substantially, creating an urgent need for efficient storage and handling of the raw materials used in the printing process. Improper storage of such materials can result in repetitive movements and awkward postures, increasing the risk of injury and reducing productivity. Therefore, applying ergonomic principles to the organization of storage areas is essential for ensuring a safe and efficient work environment.
Ergonomic evaluation tools such as RULA (Rapid Upper Limb Assessment) are valuable for identifying and quantifying risks associated with working postures. These tools allow for the analysis of body positions adopted during task performance and provide recommendations to improve working conditions [4], [5], [6].
In this context, the present study investigates the impact of ergonomically reorganizing the storage space

of raw materials used at a 3D printing workstations. By applying ergonomic principles and assessing work postures before and after the intervention, the research aims to highlight the benefits of an optimized spatial layout on both operator health and workflow efficiency.

DESCRIPTION OF THE WORKSTATION

The research was conducted within the Research Laboratory for Product Design and Development at the Faculty of Mechanics and Technology from Pitesti University Centre of National University of Science and Technology POLITEHNICA Bucharest, in a controlled environment dedicated to studying and improving additive manufacturing processes. The analyzed workstations focus on the operation of 3D printers used for prototyping and manufacturing components from plastic materials. A designated user is responsible for loading the printer with raw material, supervising the printing process, and carrying out post-processing tasks on the printed parts. The materials used include common types of thermoplastics such as PLA (polylactic acid), ABS (acrylonitrile butadiene styrene), and PETG (polyethylene terephthalate glycol), stored in containers of various sizes and weights placed on nearby shelves.

In the initial configuration, these materials were stored without any clear organizational criteria, which forced the operator to frequently stretch, reach, or bend to access the necessary supplies. This chaotic arrangement resulted in uneven physical strain and posed a risk of developing discomfort or musculoskeletal injuries when the workstation was used repeatedly.

STAGES OF THE STUDY

The study was conducted in three distinct stages, each with a clear purpose in understanding and improving the ergonomic design of the analyzed workstation:

Stage 1 – Initial Observation and Evaluation of the Workstation
In this phase, the existing configuration of the workspace was analyzed without altering the arrangement of materials or equipment. Observations focused on how the operator interacted with the environment, particularly on body postures adopted during lifting, bending, or reaching for plastic material containers. The potentially risky postures were evaluated using the RULA method, in order to identify areas subjected to excessive strain and to assess major ergonomic risks.

Stage 2 – Intervention through Workspace Reorganization
Based on the findings from the initial stage, a reorganization of the shelves and material placement was proposed. This intervention was guided by three key criteria: size, weight, and frequency of use. The aim was to relocate heavier and more frequently used materials to the optimal reach zone (approximately 80–120 cm from the floor), thereby reducing the need for awkward or physically demanding postures. Ergonomic principles were applied to simplify access, minimize reaching and bending movements, and ensure a balanced distribution of the workload.

Stage 3 – Post-Intervention Evaluation and Comparative Analysis
Following the implementation of the proposed changes, a new series of observations was conducted, and the RULA assessment was repeated to analyze the new working postures. The results were compared with those from the initial phase to evaluate the impact of the reorganization on operator strain. A significant decrease in RULA scores was observed, indicating a reduction in ergonomic risk. The operator reported a more comfortable posture and performed lifting and handling tasks more safely and efficiently.

Classification of Plastic Material Boxes și Ergonomic Placement Principles
To improve material handling efficiency, the storage boxes for plastic materials were classified based on three main criteria:
- Size: Small (S), Medium (M), Large (L);
- Weight: Light (L), Medium (M), Heavy (H);
- Frequency of Use: Low (L), Medium (M), High (H).

This classification allowed for a structured approach to reorganizing the shelving system in line with ergonomic principles.

Table 1. Box Classification Criteria

Size	S	M	B
Weight	L	M	H
Frequency of Use	L	M	H

Ergonomic Principles for Placement

To optimize efficiency and safety in the workspace, the placement of the boxes followed these core ergonomic guidelines [7], [8]:

- ***Frequency of Use***: Frequently used items should be positioned within easy reach, around waist to chest height, to minimize effort.
- ***Weight***: Heavier items should be stored on lower shelves to avoid lifting from above shoulder level and reduce injury risk.
- ***Size***: Larger boxes should be stored in lower or lateral positions to ensure stability and prevent obstructing access to other materials.

Applying these criteria, materials frequently used and of medium weight were placed in the optimal reach zone (Zone B), located between 80 and 120 cm from the floor. Lightweight or rarely used materials were placed on upper shelves (Zone C), while heavier and less-used items were placed on the lower shelves (Zone A) to minimize bending or reaching.

SIMULATION AND RULA ASSESSMENT

In the first stage of the study, direct observations were carried out to analyze how the operator interacted with the initial workstation layout. Plastic material boxes were randomly placed on the shelves, with no consideration for usage frequency or weight. The operator's body postures, the movements required to access the materials, and the time needed to identify and retrieve them were carefully documented.
Photographs and sketches were used to record the working positions. A preliminary analysis revealed several inefficient and ergonomically unfavorable movements, such as reaching above the shoulders or bending with extended legs and an arched back to pick up heavy boxes from the lower shelves.

Figure 1. Initial situation

When reaching for a box placed on the upper shelf, the operator had to raise both arms above shoulder level, with the neck in extension and the torso slightly leaning backward. Similarly, lifting heavy boxes from the lower shelves required the operator to bend forward with straight knees and a significantly inclined torso—postures that increase stress on the lumbar spine, especially when:
- the knees are not properly bent;
- the back is not kept straight;
- and the movement is repeated multiple times per day.

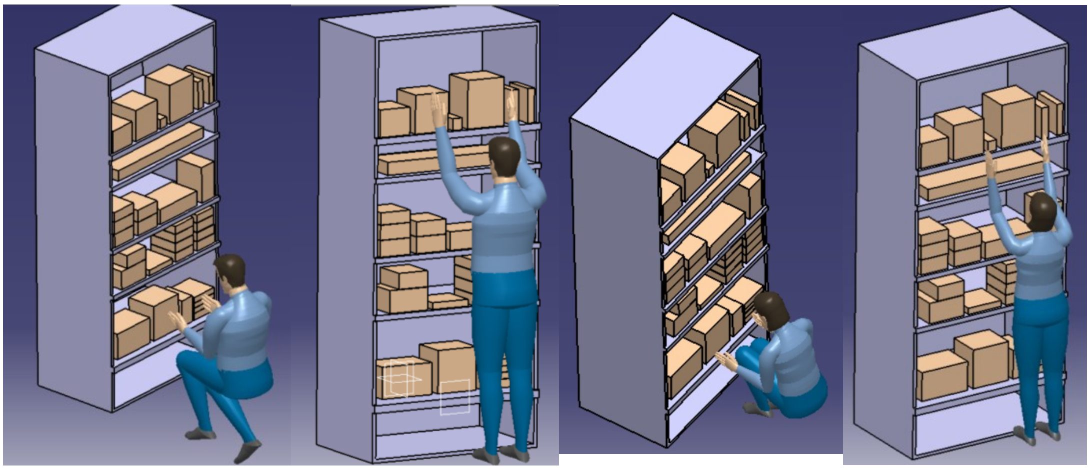

Figure 2. Workstation simulation

To analyze these postures more accurately, simulations were performed using CATIA V5 – Human Builder module. The actual workstation was modeled, and a virtual human figure was positioned in representative scenarios observed during real operation.

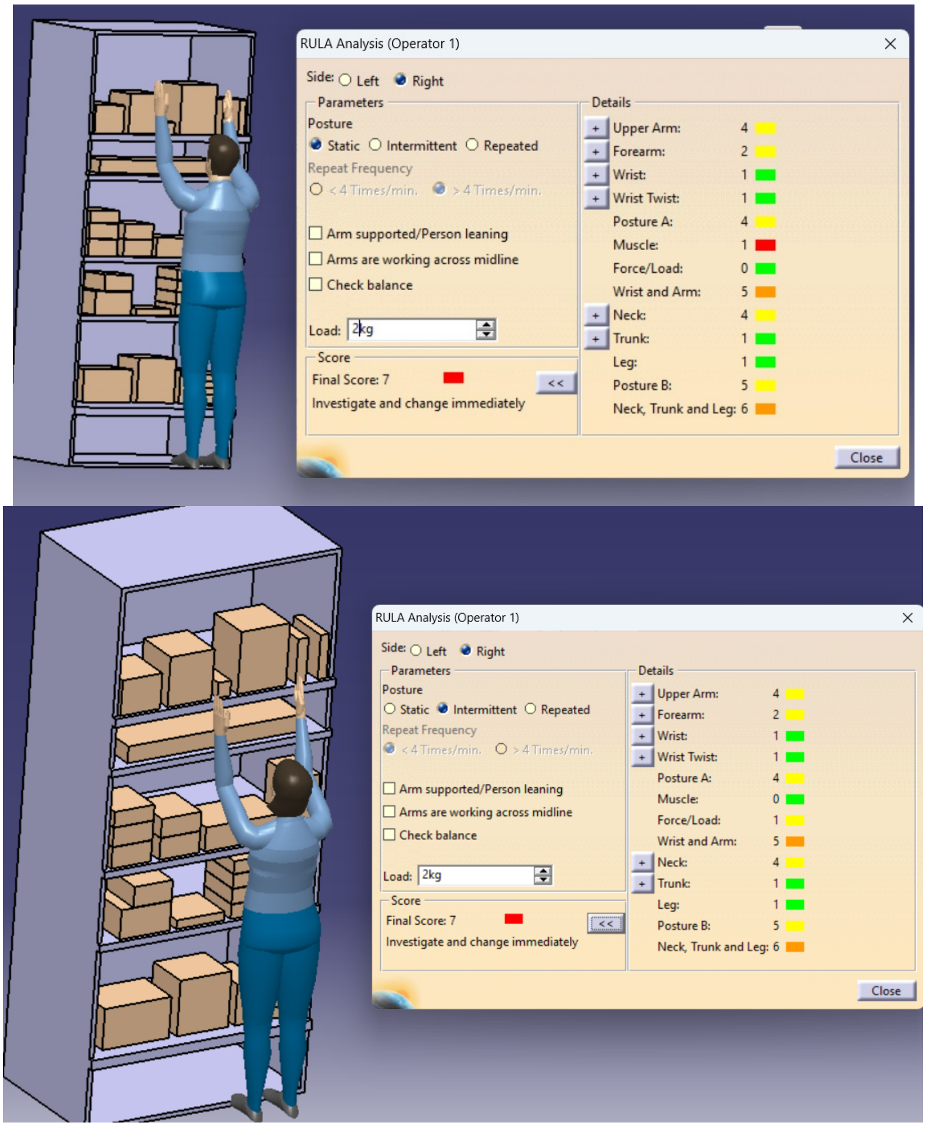

Figure 3. Applying the RULA method

The simulations illustrated:

- ***The operator's body posture*** during lifting or lowering boxes;
- ***Trunk flexion*** or arm extension depending on shelf positioning;
- ***The interaction between the operator and the shelves*** in terms of height, weight, and frequency of material access.

The goal of these simulations was to obtain a realistic representation of the operator's working postures, enabling an objective ergonomic evaluation using the RULA (Rapid Upper Limb Assessment) method.

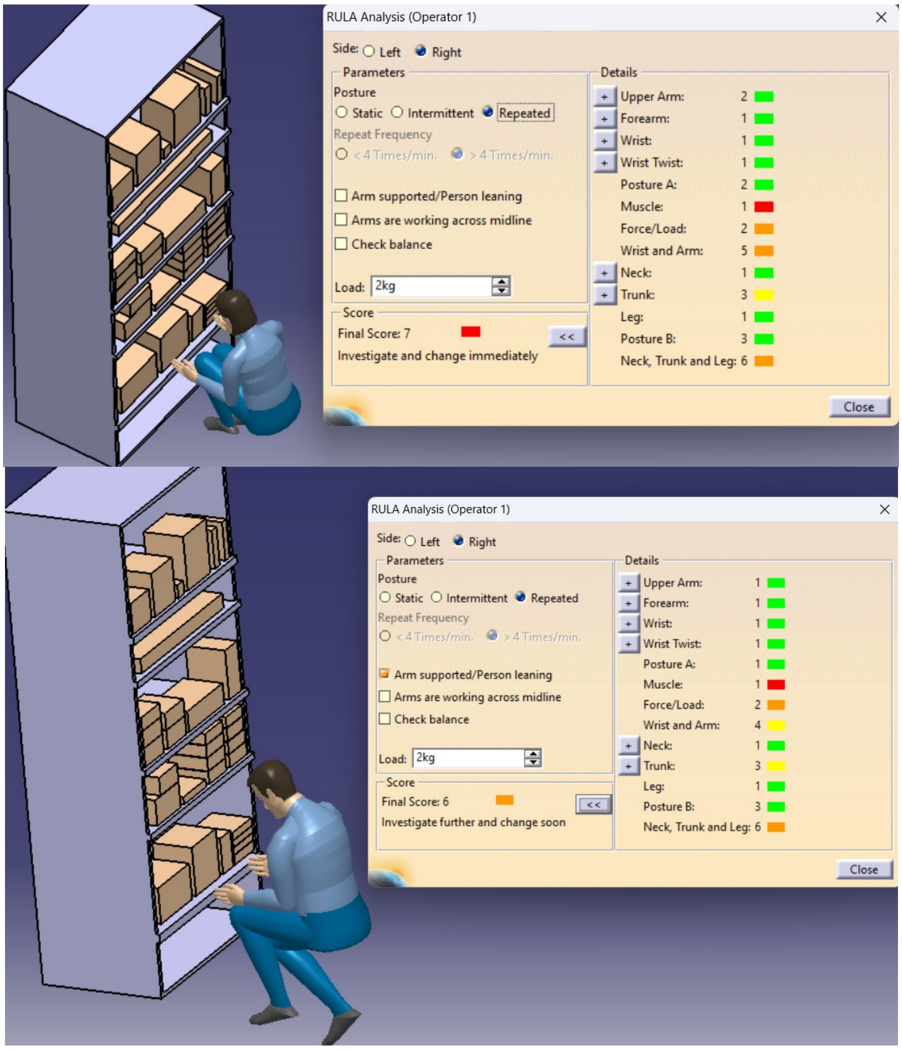

Figure 4. RULA analysis of the initial workstation

The RULA analysis of the initial workstation revealed a maximum score of 7 out of 7, indicating a very high risk posture that required immediate investigation and redesign. Despite the low weight of the lifted box (2 kg), the combination of raised arms, neck extension, and lack of arm support resulted in significant physical strain.

Specifically:
- Upper arm position: score 4;
- Trunk and neck position: score 4;
- Trunk-neck-leg interaction: score 6.

These values highlight a posture that, if adopted repeatedly or for long durations, could lead to musculoskeletal disorders.

Ergonomic Recommendations:
- Reposition frequently used boxes to the optimal working height (approximately 80–120 cm from the floor);

- Place rarely used boxes on upper or lower shelves;
- Reorganize the shelving layout based on usage frequency, weight, and size—following ergonomic storage principles.

POST-INTERVENTION RESULTS AND ANALYSIS

The second stage of the study involved reorganizing the storage space based on fundamental ergonomic principles, focusing on two main criteria: material usage frequency and weight. Materials that were frequently used and of medium weight were repositioned in the optimal working zone – (Zone B), corresponding to the operator's torso level—where access requires minimal effort and natural movements.
Lightweight or infrequently used materials were placed on the upper shelves (Zone C), while heavy and rarely used materials were moved to the lower shelves (Zone A) to reduce physical strain caused by lifting or bending.

Zones for Material Placement:
- Zone A – Lower shelves (heavy, infrequently used items);
- Zone B – Optimal reach zone (frequently used, light-to-medium weight);
- Zone C – Upper shelves (rarely used, lightweight items).

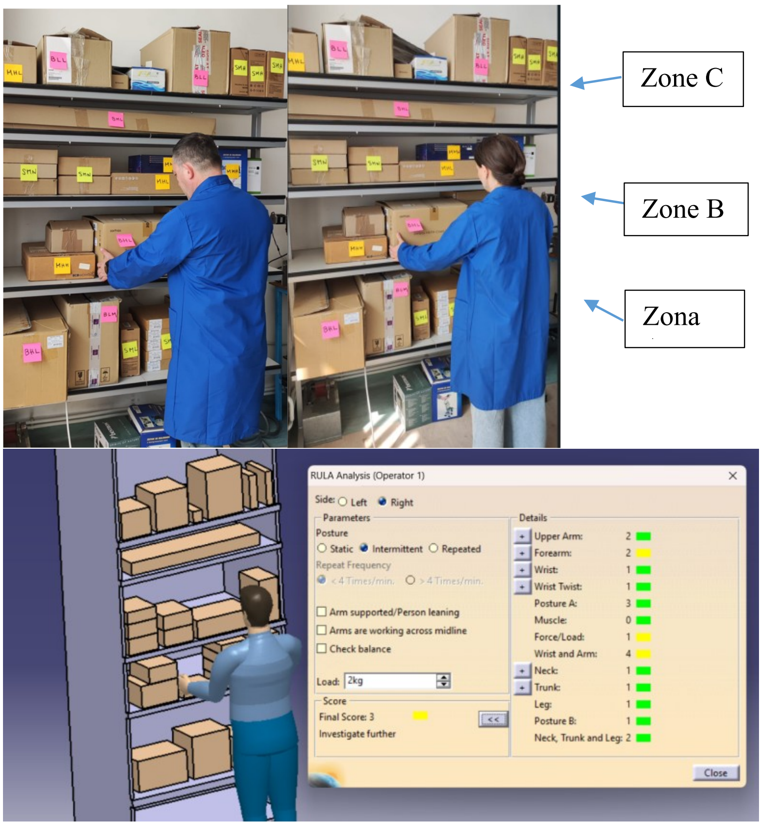

Figure 4. Improved workstation (after ergonomic reorganization)

In the third stage, the operator's posture was re-evaluated in the improved workstation configuration using the same RULA method. This step aimed to validate the effectiveness of the intervention and determine whether the ergonomic risks had been significantly reduced.
The final RULA score was 3, placing all components within the green zone, which indicates an acceptable level of physical effort and minimal need for further action.
Compared to the initial score of 7, this marked improvement confirms that optimizing material positioning and reducing awkward or demanding movements had a major positive impact on the operator's health and comfort. The posture used during material handling became more natural, balanced, and sustainable over extended periods of work.

CONCLUSIONS

The study conducted on a 3D printing workstation, focused on the handling of plastic materials, revealed from the very first stage a high level of biomechanical strain associated with certain working postures. The initial RULA assessment resulted in a score of 7, the most severe rating on the scale, indicating the need for immediate ergonomic intervention.

The operator frequently adopted awkward postures, such as:
- raising the arms above shoulder level;
- significant trunk flexion;
- and sustained muscular effort without sufficient recovery time.

Following a detailed ergonomic analysis and the application of best practices in workspace organization, the workstation was redesigned to ensure that:
- heavy and frequently used materials were positioned within the optimal reach zone (80–120 cm from the floor);
- wide arm movements and deep trunk bending were eliminated;
- and quick, safe access to all materials was guaranteed.

A post-intervention assessment using the same RULA methodology revealed a reduced score of 3, with all evaluated posture components falling within the acceptable range, implying no significant ergonomic risks for the operator.

This clear improvement—from a high-risk score of 7 to a low-risk score of 3 - demonstrates the effectiveness of ergonomic reorganization measures and highlights the real impact that intelligent workspace design can have on operator comfort, health, and productivity.

Consequently, this case study confirms that ergonomic evaluation and proper workstation design are essential in modern industrial environments, contributing to the reduction of occupational hazards and the creation of a safer, more sustainable working environment.

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