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Original Research

HAZARD IDENTIFICATION, RISK ASSESSMENT AND CONTROL (HIRAC) OF FABLAB SETTING AND INFRASTRUCTURE AT PRESIDENT UNIVERSITY

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ABSTRACT

Hazard Identification, Risk Assessment and Control (HIRAC) of Fablab Setting and Infrastructure at President University. *This study demonstrates the methodological contribution of applying the Hazard Identification, Risk Assessment, and Control (HIRAC) framework to a previously underexplored setting: an academic Fabrication Laboratory (FabLab). Key findings reveal that the facility's pre-assessment safety profile was medium-high, primarily due to critical hazards such as exposed electrical cables and obstructed emergency equipment. By employing a systematic, qualitative approach and implementing a tailored control plan based on the hierarchy of controls, the study successfully reduced the overall risk level to low-medium. The research concludes that the HIRAC method offers a replicable and effective model for proactive risk management in academic makerspaces, ultimately enhancing safety culture through structured assessment and prioritized intervention.*

INTRODUCTION

The fabrication laboratory (FabLab) is one of the essential facilities in higher education, particularly in the fields of science, engineering, and design. This facility provides students with a dedicated space to create, experiment, and develop prototypes using digital technology–based equipment, such as 3D printers, laser cutters, and precision mechanical tools [(1)]. Unlike conventional laboratories, FabLabs integrate creative, technical, and digital engineering aspects, resulting in more complex potential exposure to occupational safety and health (OSH) risks. These risks include chemical exposure from resins or solvents, physical injuries caused by rotating or sharp tools, and fire hazards resulting from electrical short circuits or overheating machinery [(2–4)].

The FabLab at President University was established on March 2, 2021, as a multidisciplinary innovation facility that integrates several engineering laboratories, including Electrical Engineering and Mechanical Engineering. The facility is supported by various laboratory equipment, such as electrical training devices, basic manufacturing machinery, digital fabrication tools, and precision measurement instruments. At President University, occupational safety and health in laboratory environments is considered a primary priority in academic development. Several educational laboratories have implemented the HIRAC/HIRA method in their practical and experimental activities [(5–7)]. However, to date, no scientific study has specifically examined the application of HIRAC within the FabLab of

President University. Addressing this research gap is essential, as FabLabs present unique risk characteristics, including potential exposure to particulate emissions and volatile organic compounds (VOCs), the use of high-speed rotating machinery, and the presence of heat sources and laser-based equipment. Although FabLabs play a significant role in supporting innovation and practice-based learning, the implementation of safety measures in these facilities is often not optimal.

Rajanen, in *Safety Culture in Digital Fabrication: Professional, Social, and Environmental Responsibilities* (8), explains that many FabLabs in higher education environments lack structured and comprehensive hazard identification and risk assessment systems. This condition is further exacerbated by insufficient safety training for users and inadequate maintenance procedures for tools and electrical systems (9). Consequently, the risk of accidents increases in line with the high intensity of student and technician activities within the workspace.

Over the past decade, several laboratory accidents have occurred on Indonesian university campuses. For instance, a fire broke out in the engineering laboratory at Universitas Brawijaya in September 2021, allegedly caused by an electrical short circuit (10). A similar incident occurred in a chemistry laboratory at the Institut Pertanian Bogor (IPB) in August 2023, resulting in a student fatality (11). Although these incidents did not directly involve FabLabs, they reflect comparable risks that could arise in FabLab environments due to the use of high-powered equipment, hazardous chemicals, and prototyping activities.

One effective approach for identifying and controlling risks in laboratory environments is the Hazard Identification, Risk Assessment, and Control (HIRAC) method. This method provides a systematic framework for identifying potential hazards, assessing risk levels using likelihood and severity matrices, and determining appropriate control measures (5,6,12). The application of HIRAC in laboratory settings has been shown to support managers in prioritizing hazard control based on the highest risk levels, thereby enabling preventive actions to be implemented efficiently and in a data-driven manner (13). Furthermore, various international studies and guidelines emphasize the importance of implementing technical control measures, such as local exhaust ventilation, emission monitoring, the development of Standard Operating Procedures (SOPs), and scheduled maintenance programs, to enhance the effectiveness of risk control (14,15).

Based on the general aim of the study, this research seeks to identify potential hazards arising from operational activities, equipment usage, and environmental conditions in the President University FabLab, to assess the risk level of each identified hazard using the Hazard Identification and Risk Assessment (HIRA) method, and to formulate practical risk control recommendations aimed at reducing the likelihood and impact of accidents within the FabLab.

Thus, the findings of this study are expected to serve as a foundation for the development of a more effective, adaptive, and measurable safety management system at President University.

MATERIALS AND RESEARCH METHODS

This study employed a descriptive qualitative approach using the Hazard Identification, Risk Assessment, and Control (HIRAC) method. A qualitative methodology was considered the most appropriate for this research, as it aims to provide an in-depth and contextual understanding of occupational safety and health risks by referring to the ISO 45001:2018 standard. This international standard emphasizes a systematic framework for managing occupational safety and health risks. Four principal clauses of ISO 45001:2018 were adopted as the methodological framework in this study.

The process began with the planning phase, which involved identifying potential risks associated with activities conducted in the FabLab hallway. This was followed by the operation phase, during which appropriate risk control measures were implemented. Subsequently, the performance evaluation phase focused on monitoring and assessing the effectiveness of the implemented control measures. Finally, the improvement phase involved the application of corrective actions based on evaluation results to ensure continuous improvement in safety performance.

The HIRAC process in this research consisted of three main stages: hazard identification, risk assessment, and risk control. This approach underscores the importance of a systematic hazard identification process, risk evaluation based on both likelihood and severity, and the establishment of proportional control measures to prevent occupational incidents (16).

This methodological approach was selected because it provides a comprehensive understanding of potential hazards in the FabLab hallway of President University, an area characterized by high pedestrian traffic and direct access to workspaces and equipment storage areas. These conditions make the hallway a critical area for assessment, as users may be exposed to mechanical, electrical, and ergonomic hazards.

Hazard Identification

Hazard identification was conducted through direct observation of the equipment layout and evaluation of equipment conditions to determine operational feasibility. Data were collected through on-site observations, review of facility documentation, and interviews with security personnel, laboratory assistants, and maintenance staff. Each identified hazard was categorized based on its source, including electrical, fire, physical, and ergonomic hazards.

Risk Assessment

Following the identification phase, risk assessment was performed using a two-dimensional Risk Assessment Matrix (RAM) that considers the factors of Likelihood (L) and Severity (S). The risk value was determined using Eq. 1 (17).

Where:

RV : Risk Value
L : Likelihood (the probability of the hazard occuring)
S : Severity (the level of impact caused by the hazard)

The assessment results were subsequently classified into four risk levels using a 4 × 4 likelihood–severity matrix, namely low, medium–low, medium–high, and high. This scale was selected for its simplicity and contextual suitability, as it provides a clear and manageable framework that is easy to implement and interpret within the operational environment of the FabLab. Moreover, this approach facilitates effective risk prioritization and is consistent with simple quantitative risk assessment methods commonly applied in previous studies (18–20).

Table 1. Risk Likelihood Categories (21)

Level	Description	Explanation
1	Very Rare	Unlikely to occur
2	Rare	Has occurred or has been heard of before
3	Frequent	Has occurred before
4	Very Frequent	Common or occurs often

Table 2. Risk Severity Category [21]

Level	Description	Explanation
1	Negligible	Minor injury requiring only first aid treatment
2	Minor	Affects work performance and requires intensive medical care at the hospital
3	Serious	Permanent disability and significantly affects work performance for a long period
4	Major	Causes death or multiple fatalities

Table 3. 4x4 Risk Likelihood and Severity Matrix ([21]

Likelihood	Negligible (1)	Minor (2)	Serious (3)	Major (4)
Very Frequent (4)	Low	Medium	High	High
Frequent (3)	Low	Medium	Medium	High
Rare (2)	Low	Low	Medium	Medium
Very Rare (1)	Low	Low	Low	Low

Risk Control

The risk control stage within the HIRAC framework aims to determine and implement appropriate mitigation measures based on the results of the preceding risk assessment. In the HIRAC process flow, this stage focuses on translating the outcomes of hazard identification and risk analysis into effective actions to manage the identified risks [17].
According to Goetsch [17], two key parameters are used in determining risk control measures, namely severity and likelihood. Severity is used to evaluate the potential for injury, occupational disease, or financial loss resulting from specific activities, whereas likelihood is used to assess the frequency of hazardous activities, the probability of occurrence, and the duration of exposure to identified hazards [22].
By integrating these two parameters, the selected control strategies aim to reduce the overall risk level to an acceptable threshold. Risk control measures may be implemented through various approaches, including elimination, substitution, engineering design, administrative controls, and the use of personal protective equipment (PPE) [23]. The effectiveness of these control measures is periodically evaluated through continuous monitoring of workplace conditions and routine hazard reporting by security personnel.

RESEARCH RESULTS AND DISCUSSION

Fablab Layout

The building layout of the FabLab at President University, Faculty of Engineering, serves as a crucial reference for understanding the spatial arrangement of laboratories, evacuation routes, and emergency facilities within the area. The layout provides a detailed visual representation of key rooms such as the 3D Printing Lab, Mechanical Engineering Lab, Electrical Engineering Lab, and Digital Prototyping Lab, along with designated hallways and exits. In addition, the map highlights the location of essential emergency equipment, including fire extinguishers and assembly points, which play a vital role in ensuring preparedness during emergency situations.
This layout was used to support the hazard identification activities conducted in the FabLab area by helping observers understand the flow of movement, potential obstruction points, and the placement of critical safety elements within the facility. By integrating the physical layout into the assessment process, the study was able to more accurately determine where hazards were likely to occur and how they might affect evacuation efficiency and overall safety. The building layout thus becomes an

important foundational reference for conducting risk assessments and developing appropriate control measures in subsequent phases.

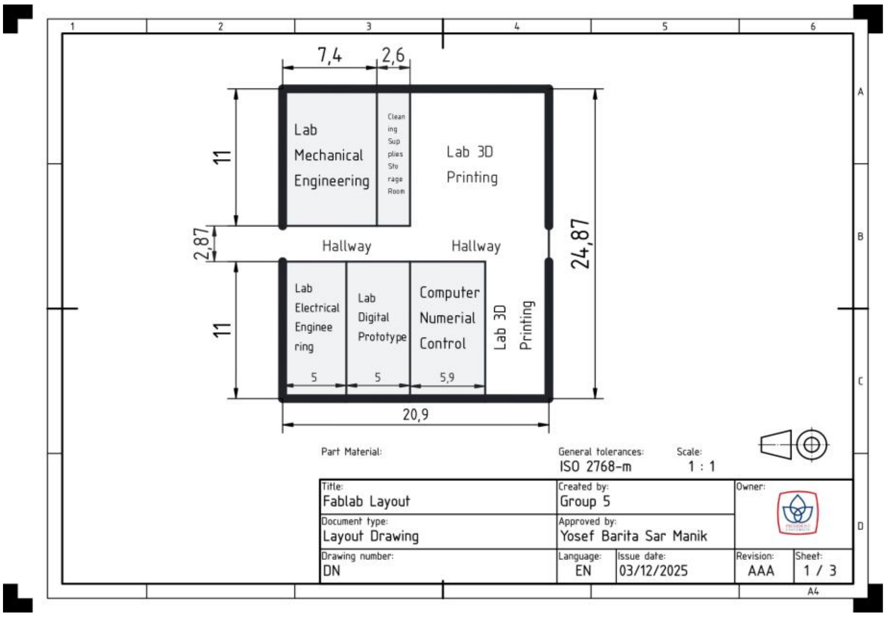

Figure 1. Fablab Layout

Hazard Identification

Hazard identification results shown in Table 4 were obtained from observations conducted on 10 September 2025 at the FabLab area of President University. The aim was to identify what potential hazards might occur during daily operations and how they could affect safety. Observations revealed several types of hazards, including electrical hazards from exposed or damaged wires, fire and life safety hazards due to blocked evacuation routes and overheating devices, as well as falling and impact hazards caused by misplaced materials and uneven flooring. In addition, temperature and noise hazards were identified around air conditioning systems. The identification process involved field observation, interviews with laboratory staff, and documentation review to ensure comprehensive detection of potential hazards that could later be analyzed in the risk assessment phase.

Table 4. Hazard Identification

No	Activity	Potential Hazard	Types of Hazard
1.	Using extension cords in the work area	• People tripping over Cables • Electrical Hazards • Risk of short circuits if cables are exposed or come into contact with liquids	• Falling Impact Acceleration Lifting and Vision Hazards • Electrical Hazards • Fire Hazards and Life Safety
2.	Placement of tables in front of fire extinguishers	• Access to fire extinguishers is blocked by tables • People rushing may trip over or bump into tables	• Fire Hazards and Life Safety • Falling Impact Acceleration Lifting and Vision Hazards
3.	Installation of air conditioner condensers facing pedestrian walkways	• Very hot air blowing directly at pedestrians • Potential dehydration/heat stress if exposed for long periods • Noise	• Hazards of Temperature Extremes • Hazards of Temperature Extremes • Noise and Vibration Hazards
4.	Cracked/broken pavement in the road area	• People can trip due to uneven floors • Broken ceramic tiles can injure feet	• Falling Impact Acceleration Lifting and Vision Hazards • Falling Impact Acceleration Lifting and Vision Hazards

No	Activity	Potential Hazard	Types of Hazard
5.	The cable is placed in the road area.	• People tripping over cables • cables can become frayed and cause electric shocks	• Falling Impact Acceleration Lifting and Vision Hazards • Electrical Hazards
6.	Movement of people through the narrow space between seats	• Risk of difficult evacuation if the seats are not arranged properly and block the hallway • Getting pinched or bumped by the seat	• Fire Hazards and Life Safety • Falling Impact Acceleration Lifting and Vision Hazards
7.	The tripod light was placed on the path.	• People may trip over the tripod, collide with it, or have obstructed movement • Spark from damaged cable insulation • People may trip over the power cable • Overheating of the lamp or cable	• Falling Impact Acceleration Lifting and Vision Hazards • Electrical Hazards • Falling Impact Acceleration Lifting and Vision Hazards • Fire Hazards and Life Safety
8.	Pendant lights are used in the FabLab area.	• The lamp is unstable, rusty, and wobbly, posing a risk of falling. • the lamp cable can break if the lamp falls	• Falling Impact Acceleration Lifting and Vision Hazards • Electrical Hazards
9.	Placing the tool in the wrong place	• Object blocking the way	• Falling Impact Acceleration Lifting and Vision Hazards
10.	The outlet is installed on the floor of the hallway.	• Passersby could trip if the socket is not properly closed. • risk of exposure to liquids	• Falling Impact Acceleration Lifting and Vision Hazards • Electrical Hazards
11.	External Factors	• Crowded event (job fair, concert, etc) • Earthquake	• Safety Hazard/Human Hazard • Falling Impact Acceleration Lifting and Vision Hazards

Risk Assessment

Risk assessment results shown in Table 5 were obtained from follow-up observations conducted on 15 October 2025 in the same FabLab area. Full details of the risk assessment for each hazard are available in the Appendix. The assessment aimed to determine how severe and how likely each identified hazard could occur, using a two-dimensional Risk Assessment Matrix (RAM) that combines Likelihood (L) and Severity (S) factors. Based on the evaluation, most hazards were categorized as medium to high risk, especially those related to electrical, fire and life safety, and falling/impact hazards. For example, activities such as handling power tools, using extension cords, or operating heated equipment posed moderate to high risks due to potential electric shock, short circuits, or overheating. Meanwhile, temperature and noise hazards were classified as low risk, as their effects were limited and well controlled. The results provide a quantitative overview of risk levels, serving as a basis for determining appropriate preventive actions and control measures to improve FabLab safety.

Table 5. Risk Assessment

No	Activity	Potential hazards	Types of Hazards	Current Control	L	AVG (L)	Hazard Consequences(s)	S	Max. S	Risk Value
1	Using extension cords in the work area	People tripping over Cables	Falling Impact Acceleration Lifting and Vision Hazards	-	4	3.33	Fall Injuries (bruises/broke n bones)	3	4	13.3 2
		Electrical Hazards	Electrical Hazards	-	3		Electric Shock	3		
		Risk of short circuits if cables are exposed or come into contact with liquids	Fire Hazards and Life Safety	-	3		Fire	4		

No	Activity	Potential hazards	Types of Hazards	Current Control	L	AVG (L)	Hazard Consequences(s)	S	Max. S	Risk Value
2	Placement of tables in front of fire extinguishers	Access to fire extinguishers is blocked by tables	Fire Hazards and Life Safety	-	2	2.5	Delayed firefighting	4	4	10
		People rushing may trip over or bump into tables	Falling Impact Acceleration Lifting and Vision Hazards	-	3		Injuries due to falling	2		
3	Installation of air conditioner condensers facing pedestrian walkways	Very hot air blowing directly at pedestrians	Hazards of Temperature Extremes	maintenance is carried out every 2-3 months	3	2.67	Discomfort to passersby	1	2	5.34
		Potential dehydration /heat stress if exposed for long periods	Hazards of Temperature Extremes	maintenance is carried out every 2-3 months	2		Minor Health issues (dehydration, dizziness)	2		
		Noise	Noise and Vibration Hazards	maintenance is carried out every 2-3 months	3		Discomfort by the noise	1		

Hazard Potential Summary

Table 6 presents the hazard potential summary compiled from the risk assessment results, highlighting which hazards require immediate attention and why they are prioritized. The analysis showed that high-risk hazards were mostly related to electrical and fire hazards, such as exposed cables, overheated devices, and blocked fire extinguisher access. Medium-risk hazards included uneven floors, unstable lamps, and improper equipment placement that could cause tripping or minor injuries. The prioritization followed the Pareto principle (80/20 rule) where a small number of key hazard types (approximately 20%) are found to contribute to the majority (approximately 80%) of the total potential risk. (24), indicating that a small number of hazard types contributed to most of the total risk in the FabLab. These results emphasize the need for preventive actions, including regular inspections, improved housekeeping, training, and proper labeling, to reduce risk exposure and strengthen the overall Occupational Health and Safety (OHS) management in the FabLab.

Table 6. Shortlist of hazard potential with medium-high level of risk assessment

No	Hazard Potential	Consequences	Level
1	People tripping over Cables	Fall Injuries (bruises/broken bones)	High
2	Electrical Hazards	Electric Shock	
3	Risk of short circuits if cables are exposed or come into contact with liquids	Fire	
4	Access to fire extinguishers is blocked by tables	Delayed firefighting	High
5	People rushing may trip over or bump into tables	Injuries due to falling	
6	People can trip due to uneven floors	Minor to serious injuries (falls, sprains, wounds)	Medium
7	Broken ceramic tiles can injure feet	Potential for more severe damage if the floor cracks further	

No	Hazard Potential	Consequences	Level
8	People tripping over cables	Injuries caused by falls (bruises, sprains)	Medium
9	cables can become frayed and cause electric shocks	Damaged equipment	
10	Risk of difficult evacuation if the seats are not arranged properly and block the hallway	Obstruction of evacuation during emergencies (e.g., slower exit in case of fire)	Medium
11	Getting pinched or bumped by the seat	Minor injuries (bruises, sprains) or falls	
12	People may trip over the tripod, collide with it, or have obstructed movement	Falls, bruises, scratches, fractures, obstruction during emergency evacuation	High
13	Spark from damaged cable insulation	Minor to serve electric shock	
14	People may trip over the power cable	Equipment damage	
15	Overheating of the lamp or cable	Fire outbreak in the area	
16	The lamp is unstable, rusty, and wobbly, posing a risk of falling.	A lamp fell and injured someone's head/body	High
17	the lamp cable can break if the lamp falls	an electrical short circuit caused a fire.	
18	Object blocking the way	People tripping and falling	Medium
19	Passersby could trip if the socket is not properly closed.	physical injuries due to falls	High
20	risk of exposure to liquids	electrocution and fire	
21	Crowded event (job fair, concert, etc)	Fall Injuries (bruises/broken bones)	High
22	Earthquake	Fall Injuries (bruises/broken bones)	

Control Plan

This section describes the control plan developed based on the results of the hazard identification and risk assessment (HIRA). The plan is structured according to the hierarchy of controls, which includes elimination, substitution, engineering controls, administrative controls, and the use of personal protective equipment (PPE) [8]. Among all identified hazards, only those classified as having medium to high risk levels were included in the control plan. Hazards categorized as low risk were excluded, as they can be adequately managed through existing routine control measures. Responsibility for implementing the proposed controls is shared among FabLab management, technicians, and users, with specific actions assigned according to each stakeholder's role and capacity.

Table 7 presents a summary of the control measures for hazards with medium to high risk levels, incorporating updated likelihood and severity values following the implementation of additional control actions. Each hazard is evaluated based on the current control measures and the proposed improvements required to reduce the risk to an acceptable level. This systematic presentation provides a clear framework for understanding the contribution of each control measure to effective risk reduction.

Table 7. Control plan for medium–high risk level hazards

No	Hazard Potential	Current Control	Current Risk Value	Elimination	Substitution	Engineering Control	Administrative Control	PPE	New Likelihood	New Severity	New Risk Value
1	People tripping over Cables	Fall Injuries (bruises/ broken bones)	13.32	Remove cables in the track area	Use wireless devices	Install cable racks, cable ducts, cable covers; additional outlets	Regular inspection & cable labeling	Closed-toe shoes/anti-slip shoes	1	3	3
	Electrical Hazards	Electric Shock		Remove/check unnecessary equipment.	Replace old equipment with SNI/certified equipment.	Install RCD/GFCI, MCB, grounding, protection panel, periodic inspection.	SOP for electricity use, maintenance schedule, electrical hazard labels.	Insulated gloves for technicians; insulated shoes.	1	3	3
	Risk of short circuits if cables are exposed or come into contact with liquids	Fire							2	4	8
2	Access to fire extinguishers is blocked by tables	Delayed firefighting	10	Keep fire extinguisher access routes clear so that fire extinguishers are easily accessible.	-	Floor markings for clear zones, clear signage.	Keep-clear policy, daily inspection of fire extinguisher access.	-	1	4	4
	People rushing may trip over or bump into tables	Injuries due to falling		Do not place tables in walkways.	Use tables with rounded corners/low-profile.	-	Pathway rules, maximum capacity, pathway signs.	Closed-toe shoes	1	3	3
3	People can trip due to uneven floors	Minor to serious injuries (falls, sprains, wounds)	7.5	Replace/repair damaged tiles	Replace with durable flooring material (vinyl)	Permanent floor repairs; mark repair areas	Regular floor inspections; report damaged areas	Anti-slip safety shoes	2	3	6
	Broken ceramic tiles can injure feet	Potential for more severe damage if the floor cracks further							2	3	6
4	People tripping over cables	Injuries caused by falls (bruises, sprains)	6	-	-	Use cable protectors/ducting to tidy up cables on the floor.	Arrange the cable layout so that it does not cross walkways; install "Watch Your Step" signage.	Closed-toe shoes (if required in the work area).	2	2	4
	cables can become frayed and cause electric shocks	Damaged equipment		Discard and discontinue use of all frayed or damaged cables. Elimination/Substitution: Replace damaged cables with new ones.	Replace old cables with new cables that have thicker insulation and meet SNI standards.	Use cable protectors, high-quality outlets, and proper grounding.	Create a schedule for regular wiring inspections.	Insulated gloves for personnel handling wiring repairs.	1	3	3
5	Risk of difficult evacuation if the seats are not arranged properly	Obstruction of evacuation during emergencies (e.g., slower	10	-	-	Create a permanent marked route with lines or floor markings.	Set up SOPs for seat arrangement + briefing before the event; install	Not applicable.	1	4	4

No	Hazard Potential	Current Control	Current Risk Value	Elimination	Substitution	Engineering Control	Administrative Control	PPE	New Likelihood	New Severity	New Risk Value
	and block the hallway	exit in case of fire)					evacuation route signage.				
	Getting pinched or bumped by the seat	Minor injuries (bruises, sprains) or falls		-	-	Ensure that all chairs are stable, not broken, and have no sharp edges	Educate users not to move chairs carelessly.	Not applicable.	1	2	2
	People may trip over the tripod, collide with it, or have obstructed movement	Falls, bruises, scratches, fractures, obstruction during emergency evacuation		-	-	Install barriers (cones) or markings on the floor around the tripod.	Place the tripod in an area that does not obstruct traffic.	Not applicable.	1	2	3
6	Spark from damaged cable insulation	Minor to serve electric shock	11	Discard and discontinue use of all cables with damaged or peeling insulation.	Replace damaged cables with new cables that have thicker insulation and meet SNI standards.	Use standard SNI cables, ELCB, MCB, and grounding.	Check cables before use.	Electrical gloves for technicians.	1	3	3
	People may trip over the power cable	Equipment damage		-	-	Use cable covers/cable ties.	Arrange cable routes so that they are not in the way of walkways,	Not applicable.	2	2	4
	Overheating of the lamp or cable	Fire outbreak in the area		-	Replace old lamps with heat-saving LED lamps.	Install adequate ventilation; use cables with appropriate load capacity.	Limit usage duration and allow cooling time.	Wear heat-resistant gloves during handling.	1	4	4
7	The lamp is unstable, rusty, and wobbly, posing a risk of falling.	A lamp fell and injured someone's head/body	10	Discard rusty or unstable lamps.	-	Install lamps on sturdy mounts and strong screws.	Conduct routine inspections before use.	Wear safety helmets if the overhead area poses a high risk.	1	4	4
	the lamp cable can break if the lamp falls	an electrical short circuit caused a fire.		-	Replace the cable with a stronger SNI standard cable.	Use a breaker (MCB/ELCB), grounding, and cable protection.	SOP for handling light installation; routine inspections.	Insulated gloves for technicians.	1	4	4
8	Object blocking the way	People tripping and falling	6	Remove objects from the main route.	-	Create a special obstacle-free route.	Issue warnings and prohibitions against placing items on evacuation routes.	Not applicable.	1	2	2
9	Passersby could trip if the socket is not properly closed.	physical injuries due to falls	10	-	-	Use a socket cover or safety wall plate.	Mandatory checks before the room is used.	Not relevant except for technical repairs.	1	3	3
	risk of exposure to liquids	electrocution and fire		Keep liquids away from electrical equipment.	Use spill-proof containers.	Protect equipment/cables with liquid-resistant protection (e.g., waterproof covers/plugs).	Enforce rules prohibiting liquids near electrical equipment.	Insulated gloves for personnel handling electricity.	1	4	4
10	Crowded event (job fair,	Fall Injuries (bruises/	12.25	-	Move to a larger venue / one with	Create clear queuing lines	Add crowd control officers + limit	Officers wear safety shoes/vests.	1	4	4

No	Hazard Potential	Current Control	Current Risk Value	Elimination	Substitution	Engineering Control	Administrative Control	PPE	New Likelihood	New Severity	New Risk Value
	concert, etc)	broken bones)			sufficient capacity.	and entry/exit routes.	the number of participants				
	Earthquake	Fall Injuries (bruises/ broken bones)		-	-	Ensure the venue is safe/earthquake-resistant and emergency exits are unobstructed.	Prepare evacuation routes + emergency procedure briefing.	Helmets/safety shoes (for evacuation personnel only).	4	4	16
	Average		9.21								4.4

The reduction in the average risk value from 9.21 to 4.4 represents a substantial improvement in safety conditions for FabLab users. Practically, this reduction shifts the overall risk profile from a medium–high level, where serious incidents were likely to occur, to a low–medium level. This transition indicates that the daily operational environment has become safer and more predictable. Users are able to operate equipment and move through the workspace with a markedly lower risk of tripping, electrical shock, or obstruction during emergency situations. The implemented control measures contribute to a more orderly, well-maintained, and systematically managed workspace, thereby fostering a safety-oriented culture in which hazards are visibly addressed and operational procedures are clearly defined. Consequently, this improvement enhances user confidence, supports productivity, and strengthens the overall reliability of the FabLab as a safe prototyping and learning environment.

These procedures reinforce safe working behavior, maintain orderly circulation, enhance emergency preparedness, and reduce the likelihood of incidents arising from human error or poor spatial organization. Overall, the combined implementation of elimination, substitution, engineering controls, and administrative measures effectively reduced the initial risk values to safer levels. Importantly, the mitigation strategy does not rely solely on personal protective equipment (PPE), but rather prioritizes higher-order controls that directly address hazard sources, improve environmental conditions, and minimize exposure for both workers and visitors.

The findings of this study are consistent with previous research that applied the Hazard Identification, Risk Assessment, and Control (HIRAC/HIRARC) framework in laboratory and technical work environments. Several studies have demonstrated that HIRAC is an effective approach for systematically identifying hazards, evaluating risk levels, and determining appropriate control measures in settings characterized by intensive interaction between humans, equipment, and infrastructure. For example, a prior study applying HIRAC in an environmental chemistry laboratory identified dominant hazards related to electrical equipment, inadequate cable management, and poor workspace organization, with most risks classified as medium to high before control implementation [5]. Similar conditions were observed in the present study, where electrical hazards, tripping hazards, and fire and life safety issues—particularly exposed cables and obstructed access to fire extinguishers—were identified as priority risks within the FabLab hallway.

Compared with laboratory-based studies that primarily focus on experimental activities, this research extends the application of HIRAC to a transitional space, namely the FabLab hallway, which is frequently overlooked in occupational safety assessments. Previous studies have largely concentrated on production laboratories and industrial workshops, where hazards are predominantly associated with machinery operation and direct work processes [6,20]. In contrast, the present study demonstrates that circulation areas may present comparable levels of risk. The pre-control risk values identified in this study, with an average risk score of 9.21, are comparable to those reported in workshop and laboratory studies employing the

HIRARC method, indicating that non-production areas can significantly contribute to overall safety risks if not adequately managed.

Furthermore, the application of a 4×4 likelihood–severity risk matrix in this study enables clearer and more structured hazard prioritization compared with studies that rely on broader qualitative classifications such as low, medium, and high risk. Although numerous studies conducted in fabrication and laboratory environments have employed the HIRAC or HIRARC approach, many do not clearly describe the dimensions of the risk matrix or the severity scales applied [6,20,25]. These limitations underscore the importance of a transparent and systematic risk assessment framework, such as the explicit use of a 4×4 likelihood–severity matrix adopted in the present study. This approach facilitates more transparent risk evaluation and allows for meaningful comparison between pre- and post-control conditions. Following the implementation of control measures based on the hierarchy of controls, the average risk value decreased from 9.21 (medium–high) to 4.4 (low–medium). This level of risk reduction is comparable to, or greater than, those reported in previous HIRAC-based studies conducted in laboratory settings [5,15]. These findings further confirm the effectiveness of prioritizing engineering and administrative controls over exclusive reliance on personal protective equipment in achieving sustainable risk reduction.

CONCLUSIONS AND RECOMMENDATIONS

This study demonstrates that all research objectives have been successfully achieved. First, various potential hazards in the President University FabLab were systematically identified across its operations, equipment, and environment, including electrical, fire, tripping, ergonomic, and environmental risks. Second, the risk level of each identified hazard was assessed using the HIRA method and a Risk Assessment Matrix, revealing priority areas such as exposed cables, obstructed fire extinguishers, and unstable equipment, which were classified from low-medium to medium-high risk. Third, practical risk control recommendations were formulated, focusing on these higher-risk hazards and structured according to the hierarchy of controls from engineering solutions to administrative procedures to effectively mitigate accident likelihood and impact.

The application of the HIRAC method proved effective in structuring this process, strengthening the foundation for a more adaptive and proactive safety management system within the FabLab. It should be noted that this study has certain limitations, primarily its focus on a single FabLab location and its reliance on observational and self-reported data at a specific point in time. These factors may affect the generalizability of the findings. Nevertheless, the systematic approach taken here successfully addressed each research objective and provides a replicable model for ongoing risk management and safety enhancement in similar digital fabrication environments.

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