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SAFETY ASSESSMENT FRAMEWORK OF DESKTOP 3D PRINTERS

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ABSTRACT: The influx of consumer-scale 3D printers in the market in recent years had seen many such desktop-based machines going into schools, homes and offices. However, there are open questions about the use of desktop 3D printers, with no specific standards directly associated with these products currently. In this paper, a qualitative safety assessment framework has been developed based on a Hazard Based Safety Engineering (HBSE) approach. It encompasses wide ranging aspects of the usage desktop 3D printers. These would help to determine the important criteria to consider when adopting 3D printing technologies.

KEYWORDS: Safety Assessment, 3D Printing, Additive Manufacturing, Risk Assessment

1. INTRODUCTION

3D printing had been previously used in industrial applications to create product prototypes due to its capacity to customise and fabricate models of complex designs [1]. An increased attention in 3D printing as a major disruptive technology in recent years saw it moving into the consumer market in the form of low-cost desktop 3D printers. However, 3D printing is still considered a novel technology and a mass majority are not familiar with its use and operation. This paper aims to determine the important criteria to be considered when introducing 3D printing technology to the mass market. This research is needed as there are projections of massive adoption of the technology worldwide over the next few years, yet there are open questions about the safety of desktop 3D printers, with no specific standards directly associated with these products [2]. A systematic assessment of the safety aspects of 3D printers would be conducted using hazards-based safety engineering (HBSE) approach.

2. CURRENT STATE OF TECHNOLOGY AND SYSTEMS

The predominant systems on the desktop 3D printer market uses mainly the Fused Filament Fabrication (FFF) process. Yet the market is constantly evolving and it is fast becoming a dynamic industry where new systems, materials and processes are uncovered profusely. FFF alone come in different forms, such as the open case, the enclosed and also multifunctional ones. In the recent years, there has been new entrants like Stereolithography (SLA) and Selective Laser Sintering (SLS) techniques as well.

3. HAZARD BASED SAFETY ENGINEERING (HBSE) APPROACH

The hazard-based approach, specifically adapted from safety standard ISO/IEC 62368-1 [3], provides a base reference framework for the assessment of desktop 3D printers.It involves risk assessment to identify, analyze and evaluate the risk of each hazard, and design of appropriate safeguards to reduce the risk of injury [4]. The essence of the approach is that any product that causes injuries must involve the transfer of energy to or from a body part as illustrated by the three-block model in Figure 1. As injury requires energy transfer, the focus was to identify energy sources within the 3D printer, quantifying the magnitude of the energy sources, transfer mechanism, and the effect on the users.

Figure 1. HBSE three-block model energy transfer model

A fault tree model can be used to break it down to a two-step process: (1) Specify undesired event that may happen when working with the 3D printer, and (2) Analyse the system in the context of its environment and operation to find all the credible ways in which the undesired event can occur [5]. It is graphical model of the parallel and sequential combinations of faults that will result in the occurrence of any pre-defined undesired event. The faults can be interrelated events which can contribute to the undesired event.

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3.1 Fault Tree Charts of Undesired Events

The following events have been identified as the most undesired events to occur for the use of desktop 3D printers.

- Electrically-caused fire
- Electrically-caused injury
- Mechanically-caused injury
- Thermally-caused injury
- Radiation-caused injury
- Injury caused by hazardous substances
- Breach in software security

A fault tree is drawn with the undesired event at the top, and the faults leading up to it can be events that are associated with any 3D printer component hardware failures, software/firmware failures, human errors, or any other pertinent events which can lead to the undesired event.

3.2 Electrically-caused fire

Fires may be caused by electrical faults, combined with the presence of ignition source and concentration of oxygen, shown in the fault tree in Figure 2. Examples of electrical faults and their triggers are as follow:

i) *Short Circuit* - Any faults in the wiring is dangerous when electrical energy passes through the wires.

ii) *Overloaded Electric Cables* - For 3D printers that require power source to operate, the use of an incorrect fuse or wiring may cause overloaded electric cable when there is a surge in voltage.

iii) *Concentration of Pyrolytic Gases* - There are release of gases by material during printing processes and the build-up of these gases within the system may pose a danger for the fire or explosion to occur.

iv) *Battery Unsafe for Operation* - For 3D printers with remote power source, the safety regarding the use of batteries are important. In the case of vented volatiles from cells and electrolyte leakages, the release of toxic gases as well as the presence of fuel will be a potential ignition point for the fire breakout.

v) *Flammable Material* - There are 3D printers that utilises flammable materials such as resins. The occurrence of fires from the ignition or spark nearby such materials may be a hazard too.

![Fault tree of electrically-caused fire](image_url)

Figure 2. Fault tree of electrically-caused fire
3.3 Electrically-caused injury (Electric shock)

Electric shocks can be caused by electric faults, coupled with users coming into contact with a conductive body of the 3D printer, and also improper insulation between the contact points/surfaces. The fault tree analysis is depicted in Figure 3. Examples of electrical faults and their triggers are as follow.

i) **Overloaded Cables** - May be caused by the use of adaptor that is of the incorrect voltage.

ii) **Highly-Charged Metal Parts** - In the presence of electrical energy from the mains, any highly charged metallic part is a hazard to the user.

iii) **Incompatible Plugs** - The risk of having an incompatible or faulty fuse in the plugs may cause electrical surge when high voltage from the mains is applied.

iv) **Outer Casing not Insulated** - Any ungrounded metal casing may be a hazard.

v) **Poor Waterproofing Design** - Any 3D printer may come into contact with water in its surroundings may incur electric shocks to users if waterproofing design is not done properly.

vi) **Cable Defects or Damage** - Having exposed conductors due to probable gaps in cable insulation is a risk.

![Fault tree of electrically-caused injury](image)

Figure 3. Fault tree of electrically-caused injury

3.4 Mechanically-caused injury

Many desktop 3D printers use mechanisms like the gear and belt systems. Such systems may pose a danger if there is body contact and improper safeguards. Especially in a home environment, safety should be robust.

i) **Sharp Edges** - Manufacturers should look to reduce the number of sharp edges/corners in both the interior and exterior of the printer. Unnecessary sharp edges should be avoided, and protective guard should be in place for those that cannot be avoided.

ii) **Exposed Moving Parts** - Especially those with clearance gap big enough for finger to enter, is dangerous.

iii) **Exposed Fittings** - Exposed fittings can also be a hazard especially in areas whereby users are likely to come into much contact easily.

iv) **Cracks** - A structure that cracks easily is a safety hazard.

v) **Instability of 3D Printer Frame** - A misaligned 3D printer may topple over in the event of vibration or external force, and may cause injury.
3.5 Thermally-caused injury

The use of high thermal energy is commonly seen in desktop 3D printers. Thermally-caused injuries are mainly the result of energy transfer through conduction, convection and radiation.

i) *Conduction* - High energy transfer through exposed hot surface will cause burns when there is a direct body contact and sufficient insulative cover or gear.

ii) *Convection* - For enclosed 3D printers, the hot gases emitted from printing may build up and concentrate. If these gases are released upon opening of the enclosure, there may be danger of scalding occurring.

iii) *Radiation* - Thermal radiation through of high emissivity surface may cause injury through when there is insufficient protective cover. Hence, the design of protection and choice of material and is important.
3.6 Radiation-caused injury

Processes with laser or/and UV light, such as SLA and Direct Light Processing (DLP), have radiation related risks. Injuries may be caused by poorly designed protective cover, and prolonged exposure to optical sources.

i) Direct exposure to laser/UV light - Alignment and protection of the lens or light source should be proper.

Figure 6. Fault tree of radiation-caused injury

3.7 Injury caused by hazardous substances

During melting, curing or phase changes of polymers, there may be toxic substance produced. Prolonged direct contact to materials, like resins, may also be health damaging. Safeguards should be in place to mitigate these.

i) Bodily Exposure to Toxic Materials - Poor storage or cover design may lead to material or resin spillage. Improper handling, and failure to wear the right protective safeguards, would also make this a hazard.

ii) Inhaling Toxic Substances - Safeguards from the inhalation of toxic fumes/particles/substances produced from printing is increasingly important as more materials become available for 3D printing.

Figure 7. Fault tree of injury caused by hazardous substances
3.8 Breach in software security

3D printers are exposed to the risks in software security not dissimilar to that faced by computers. Interconnection with the other communicative devices and computers through internet and wireless technology may bring about huge perks, such as remote tracking, or print downloaded files straight from web browsers. However, the flipside are dangers as depicted below.

i) Hacker gained control of 3D printer - Malicious hackers may perform deliberate intrusion to the device and gain control of the system and affiliated machines, if software code and security is poorly designed.

ii) Malfunction of Software - Poor design may cause a system breakdown upon the failure of safeguards.

iii) Unauthorized Modification of Firmware - Non-malicious hacks are common as users look to maximise the capacity of the machine. However, if incorrectly done, this may lead to accidents.

![Fault tree of breach in software security](image)

Figure 8. Fault tree of breach in software security

4. CONCLUSION

The adoption of 3D printers in mass market is already underway, and will likely accelerate as more people become familiar with it. The speed of innovation, and rapid change in lower cost technologies, make assessing the acceptability of specific machines hard. Different processes present different hazards that require mitigation. Hazards from heat, chemical exposure, mechanical forces and sharp objects are common. A hazard-based approach, specifically ISO/IEC 62368-1, provides a strong framework for assessing the safety of 3D printers.

5. REFERENCES


