Evaluation of Suitability of Rapid Prototyping Techniques for Use by Children

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***Abstract*—Technology that facilitates rapid prototyping and rapid manufacturing has become increasingly available to the ordinary user in the home, the office, or at school. These rapid prototyping technologies should make it possible to offer school children the opportunity to design and then realise three dimensional (3D) objects. One of the perceived benefits of this is that children can become more involved in the process of producing 3D objects. Unfortunately, because of the nature of the available of the technology, and the issues associated with access to materials, adult help, supervision and assistance are often required, depriving children of the opportunity to create and produce freely, taking ownership of the process.**

This study evaluates the different techniques and materials available to children, highlighting their benefits and limitations, and reaching a conclusion about which materials and techniques are the most suitable for achieving a child-led approach to production. The study concludes that Cubify Cube is the most appropriate solution in terms of ease of use, not requiring adult assistance or supervision or the realisation of designs.

Keywords—children, design, products, manufacturing, prototype, independence

I. INTRODUCTION

When children are engaged in creating objects in an art and design setting, adults typically have some input into the process, to facilitate the use of materials and technology. This study endeavours to find suitable materials and techniques for use by children, which will allow them to be more involved in the production process and to avoid dependence on adults. Specifically, this will allow children to take ownership of more of the design and production process, enabling them to become more enterprising in the design and manufacture of products.

The reasons that adult help and supervision is often required when children are using sophisticated techniques, such as 3 D printing, are that children do not have the required knowledge and skills to use the equipment, and certain processes and materials may not be safe for children to use.

Therefore, the solution to this problem, and one way to allow children greater ownership of the production process is to find materials and techniques that are suitable for children to use. This study examines 3D printing technologies and materials that are suitable for children, and demonstrates their suitability by describing a practical exercise.

The study considers 3D printing as one of the newest technologies available to help children realise their designs by producing real 3D objects; moreover, the technology is becoming increasingly available for use in the home, and is becoming easier to use.

II. PRELIMINARIES

A. *3D History and Development*

Additive manufacturing is a process that supports the manufacture of objects using computers. It dates to the 1980s, and the basic concept behind the process is the addition of material to make objects, as opposed to earlier process that removed material to make objects [1].

[2] states that, although 3D printing was originally only for tech-savvy engineers, it is now an off-the-shelf technology available to everyone. 3D printing is also sometimes referred to as digital fabrication and is considered to be a technological revolution with applications in many areas, including business and education [1]. These ideas are echoed [3], who has commented that 3D printing is no longer the domain of engineers, as all disciplines can benefit from the technology.

A new type of designer has emerged with the introduction of 3D printers as a personal manufacturing tool. These designers do not need to have the skills for CAD, and include artists, casual designers and children [4]. [5] believes that the use of 3D printing technology will become more widespread, and that it can be used anywhere to allow children control over processes enabling them to print their own personalised objects, or objects for others.

B. *Children and 3D Design*

[6] suggests that it is important to acknowledge the ability of children to produce three-dimensional designs, because it has been an aspect formerly neglected, impeding children's creativity. Children are asked to be creative by engaging in drawing or painting, because materials are readily available, and educators and psychologists have used these pictures to understanding children's psychology and development; unfortunately, however, three-dimensional development has been neglected, educators have had limited opportunity to provide children with the tools to explore three-dimensional design [6].

As was previously the case with computers, people once thought that children would not use 3D printing. However, children are using 3D printers [5]. [5] also states that 3D printing should be used beyond the classroom similar to other technologies. Examples of this development were included in a study carried out [7], in which children were given the opportunity to be creative and engage more in the design process by utilising rapid prototyping technology.

In a study [8] 3D printing technology was combined with other technology to allow children to be more technically creative. This involved allowing children to create a functioning robot combining electronics and 3D printing. The important benefit of the study was that it allowed children to create prototypes using 3D printing, which introduced them to concepts associated with reconfiguration and adaptation, ideas sharing, and design innovation [8]. In relation to this, [5] observes that children should have a feeling of optimism and enthusiasm about the potential of their work; however, until recently this has not been the case.

[5] also stated that although it may seem frivolous when children are engaged in printing playful materials, this allows for 'sparking designers' imaginations' [5]. [5] notes that there are numerous possibilities in relation to the fabrication tools and projects that can be proposed for children, and suggests practical tasks such as: printing out construction pieces, printing pieces for model railways, jewellery, furniture, pieces for games and souvenirs.

C. *Additive Manufacturing*

[9] defines rapid manufacturing as 'the use of a computer aided design (CAD)-based automated additive manufacturing process to construct parts that are used directly as finished products or components' [9]. Although rapid prototyping systems can be used to make end-use parts, they are unsuitable for manufacturing because of problems with surface finish and accuracy [9]. Additive rapid prototyping is an encompassing term, which includes the techniques used to make parts layer by layer, including stereolithography, fused-deposit-modelling (FDM), ballistic-particle manufacturing, laminated-object manufacturing, three-dimensional printing and selective laser sintering [10].

III. METHODOLOGY

The overall aim of the study was to determine what would be the most suitable technology and materials for children to produce 3D objects based on their designs. Specifically, the techniques and materials should not only be suitable in terms of ease of use and safety, but should also allow children to take ownership of the production process. Considering this aim, the methodology of the study was designed in two parts; firstly, a review of the available techniques and materials and their suitability for use by children, and secondly a practical exercise in which children were given the opportunity to use the chosen techniques to produce their designs as 3D objects.

IV. 3D PRODUCTION TECHNIQUES

This section provides an overview of the techniques and materials used for the purpose of evaluation for suitability of use by children in an independent design process.

A. *Principles of Shaping*

When shaping 3D objects there are three main techniques available; these are subtractive and forming processes, and additive manufacturing (Figure 1), as presented below

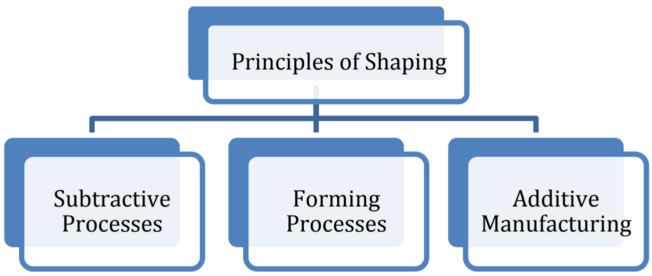

Figure 1. Principles of Shaping

Subtractive processes

Subtractive processes involve manufacturing a prototype using tools and machines to remove material; this process often involves using computer-based technology to create three-dimensional representations of the part to be manufactured (Kalpakjian & Schmid, 2006). Unfortunately, there are two main reasons why this technique is unsuitable for children; firstly, because it requires extensive machinery which may not be safe for children to use and is not available in schools, and secondly because a level of skill and training is required. Importantly, it is unsuitable for the present study as it is a time consuming process.

Forming Processes

Forming processes involve materials formed using different techniques, which include stretching, bending, folding, rolling and heating. Not only do these processes require a certain level of skill, meaning that children find it difficult to accurately render their original designs into 3D objects; in addition, as with subtractive processes, some of the equipment could be unsuitable for use by children.

Additive manufacturing

Additive manufacturing (Injection moulding) involves forcing granulated material through a heated cylinder into a mould. Cups, toys and drawers or door knobs are common items made using this method [10]. Although this method has advantages, the initial mould is very costly to make and injection moulding is only justifiable on an industrial scale, and is therefore unsuitable for use by children.

V. Additive Manufacturing - Rapid Prototyping

Generally, rapid prototyping involves the building of objects layer by layer, and is often termed 'additive' manufacturing [9]. This technique has a number of implications that should be considered when assessing its suitability for use by children. Firstly, these techniques often use advanced software to provide the computer with a CAD file of the part to be manufactured [10]. Secondly, although the majority of the process is automated, the user does have to set up the software, start the machine, and finish the surface by hand once the product has been manufactured.

A. *Material types of additive manufacturing*

It is important to consider the different types of materials and evaluate them against the their potential for use by children. A number of techniques within additive manufacturing are determined by the type of material used; these include liquid-based, powder-based and solid-based techniques (Figure 2).

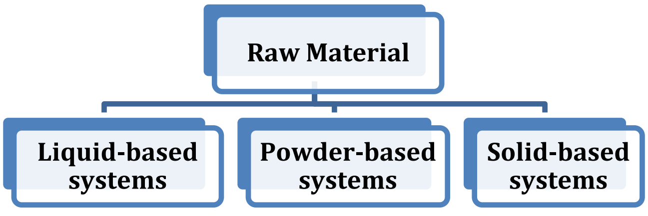

Figure 2. Raw Material

Liquid-based systems

In liquid-based systems a solid is formed by curing specific areas of a photosensitive polymer. Liquid-based systems, a well-known example of which is stereolithography, are considered to be the forerunners of rapid prototyping (RP) technology. While there are no issues directly related to these systems in relation to use by children, the overall properties of the materials are poor, specifically as regards ageing and exposure to sunlight, appearance, and mechanical properties [9].

Powder-based systems

When using powder-based processes the disadvantages of liquid-based processes are overcome, as they provide better stability and material properties. Moreover, powder-based processes offer a wide choice of materials including polymers, metals and ceramics. Selective laser sintering (SLS) and Z Corp (3D printer) are two examples of powder-based systems. Children find all the strategies are difficult when using this technique, specifically, preparing the machine and materials, removing the object after printing and finishing the product, which includes numerous processes, moreover, protective face masks have to be worn to avoid particle inhalation.

Solid-based systems

Solid-based systems use solid raw materials, and are commonly used in rapid prototyping. There are two main systems used within the solid-based approach: fused deposit modelling (FDM) and laminate object manufacturing. FDM was chosen in this study for use by children, an explanation of this choice is provided below.

VI. Results And Discussion

Based on the above review appropriate methods and materials were chosen as suitable for use by children. Fused Deposit Modelling (FDM) was selected from the techniques available for 3D printing. FDM builds three-dimensional objects by extruding a thermoplastic polymer through a nozzle; in this way layers are added to one another to build the object.

In relation to use by children there are a number of advantages to this technique. Firstly, it is easy to set up and suitable for office and school environments [9]. [11] state that there is little need to clean the object after printing has finished. Moreover, it is easy to remove the supporting material by breaking it of or washing it away.

[11] drew attention to a number of disadvantages with using FDM technology, which include restricted accuracy because of the shape of the material, the slow nature of the process, and the potential for unpredictable shrinkage. However, these disadvantages are not detrimental for children using FDM technology, because the study endeavours to allow children to create designs for artistic purposes, allowing them to realise and visualise their designs. The restrictions associated with the lack of an excellent finish and length of the process is more pertinent to commercial processes.

Although there are a variety of materials available for use with the FDM technique, including polyphenylsulfone and polycarbonate, the most widely used materials are acrylonitrile butadiene styrene (ABS) and PLA (Polylactide).

The FDM technique is especially suitable for use with ABS because it does not require post curing or support; this is provided by the overhangs as the material sets [12]. This is an important advantage when the material is being used by children, as it means there is less to do and fewer skills required after the object has been printed. ABS also has high impact resistance and is good at absorbing colour [12]; this is important, as some of the objects created by the children will be toys. A well-known example of ABS being used for toys is Lego.

In terms of toxicity, although ABS contains an acrylonitrile monomer, which is highly toxic, when polymerised with styrene it becomes completely harmless [12].

PLA is a thermoplastic like ABS and is widely used in 3D printing. In comparison to ABS, PLA results in less warping and more detail in the corners and is stronger than ABS [13]. PLA is eco-friendly because it is made from plant materials and is biodegradable. A recent development, demonstrating that PLA may be better than ABS for objects to be used by children, is that the Lego Group are considering replacing ABS with PLA [14].

In summary, it can be concluded that while ABS is stronger and more durable, PLA is more cost effective, and is biodegradable and recyclable. Moreover, because PLA has a lower melting temperature, it is safer than ABS, which has to be extruded at a much higher temperature, making it less safe for use by children [15].

A. CAD (Computer-aided design)

Although there are a number of child-friendly printers available, as detailed above, there are two main concerns in relation to their use by children. Firstly, although CAD technology can be used by children, they still have to learn how to use the technology, which can take some time; and secondly, often CAD programs that are designed for used by children only offer block style shapes, which significantly restrict the design possibilities.

B. Cubify Cube

After consideration of the different techniques and materials available for use by children in an independent design and production process, it was decided the most suitable 3D printer was the Cubify Cube. This printer was designed for ease of use, with children in mind. The above appraisal of techniques and consideration of materials informed an approach that would enable children to produce 3D designs without the help of adults. Specifically, the Cubify Cube is suitable in terms of cost, safety, reliability, suitability for use in the home or school and overall resolution.

More specifically, the advantages of the Cubify Cube include that the set-up and installation of the cartridge is very easy, the overall set-up time is quick, maintenance is straight-forward, and a glue-based adhesion system makes it easy to remove the printed object when finished [16]. Moreover, the Cube has a touch-screen interface, offering a wide range of colours and uses for both ABS and PLA. Importantly, the Cube has been certified by the manufacturer as safe for use by children.

C. cube software

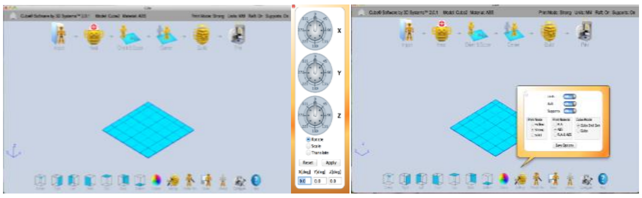

Figure 3. Cubify Software

Cubify software (Figure 3) is very simple and easy to use in comparison to other, often complex 3D-printing software. It has a simple icon-based system which shows the user how to import a 3D design file and position the design relative to the build surface. Another feature is that the designs can be sent to the printer via Wi-Fi.

D. Practical Exercise

As a mechanism to validate the results and to ensure that the appropriate methods were chosen a practical exercise was carried out with children. The children in this study (9-12 years) were afforded the opportunity to use the Cubify Cube in a practical situation in order to evaluate its ease of use. The children were first asked to create designs in the CAD program provided with the Cube. This allowed the children to utilise its various functions, such as stretching and warping the designs, and also helped them to understand the relationship between the CAD rendering and the physical object.

Thereafter, the children set up the machine by themselves; this included adding the material cartridges and preparing the build surface. The children were fully in control of the process and of setting the machines to print their objects. Once the objects had been printed, the children removed them from the printing surface and removed any unwanted materials.

Overall, the practical exercise was a success and the children produced a number of unique and interesting designs. There were some issues with the quality of the finish; however, this was related to the technology and not the actions of the children. Below (Figures 4) are examples of some of the objects that the children achieved:

Figure 4. Model of Chainsaw Tank, Cube

An informal discussion was held with the children after the practical exercise in order to ascertain if they had encountered any problems with the technology and materials; specifically, the discussion sought to determine if the Cube was easy and safe to use and if the materials were suitable. The children said that there were no problems with the technology and at no point did they feel the need to ask for an adult's help.

More importantly, during the discussion, the researcher asked the children questions about how they felt generally in terms of their ownership of the process. All of the children reported that they felt independent and in control of the process, and that this sense of responsibility motivated them further.

VII. Conclusion

Originating in recognition of the need to allow children to be more involved in rapid manufacturing, and granting them ownership of the process, this study aimed to evaluate the various techniques and materials that would be suitable for use by children. The study revealed that the most suitable approach was FDM, because of its ease of use and the lack of requirement for specialist skills. Moreover, the study also established the most suitable materials, suitable for use by children, namely ABS and PLA.

The study revealed that even within the FDM technique, when using 3D printers there were still limitations place on children in terms of the need for them to have the skills to create CAD renderings and the skills required to set up and manage the printer. Fortunately, the Cubify Cube addresses these concerns, and so was deemed the most suitable technology to allow children to take ownership of the design and production process.

The study has significant implications for the world of design and manufacturing and opens new possibilities to allow children to independently manufacture their own designs without the need for adults. This combined with independent design by children will bring a new design paradigm through completely child-led processes.

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