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Study of additive manufacturing techniques to obtain tactile graphics

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Abstract: Tactile graphics (TG) are intended to facilitate communication for people with total or partial visual impairment. For this purpose, TG include elements in relief that can be perceived through the sense of touch. TG can be fixed or portable. Fixed TG are expensive, as they are typically produced in very short runs, mostly single part production. Portable TG can be made by thermoforming polymer sheets, but a mould is still required, even though production runs are short (some tens). For this reason, the use of Rapid Manufacturing (RM) and Rapid Tooling (RT) strategies to manufacture TG can be of great interest. In this work, a literature review to study the application of Additive Manufacturing (AM) to obtain TG, both as RM and RT, is carried out. The review reveals the suitability of AM techniques to manufacture TG. In addition, some AM techniques are analysed to be used for a new type of TG, which is based on the deposition of glaze on ceramic tiles.

Keywords: Tactile graphics, Additive manufacturing, Rapid manufacturing, 3D printing, Visual impairment.

1. Introduction

The main purpose of tactile graphics (TG) is to ease communication for people with total or partial visual impairment. For this purpose, TG make use of relief elements for haptic perception (sense of touch). In addition, TG frequently contain graphic information and flat text, so that they can also be used by people without visual impairment. The relief elements, which should be appropriate for haptic perception, include different types of: lines (thick line, thin line, continuous line, broken line, dotted line, etc.), textures, symbols, as well as literacy Braille code. The most common TG are the so-called orientation TG. They are used both for urban orientation (containing streets, squares, buildings, etc.), and for the interior of buildings (containing rooms, walks, elements at different levels, etc.).

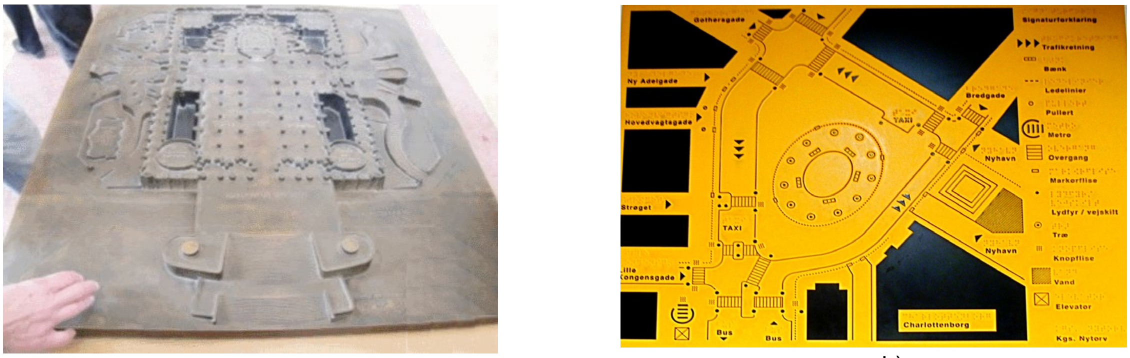
According to durability, TG can be classified into two groups:

- *Fixed or permanent Tactile Graphics*. These TG have a permanent location and require a high durability. For this reason, fixed TG are usually rigid and made of materials with high resistance to wear and cleaning products. For outdoors applications, materials used for fixed TG must also be resistant to weather conditions (ultraviolet radiation, high temperature changes, dirt, etc.). Therefore, fixed TG are typically very expensive.
- *Portable Tactile Graphics*. Portable TG are single-use TG and are carried by the user. The user will let the portable TG rest on his/her body trunk to proceed with the haptic perception.

Therefore, portable TG must be lightweight, small in size (at most A3) and flexible, as well as a low-cost product.

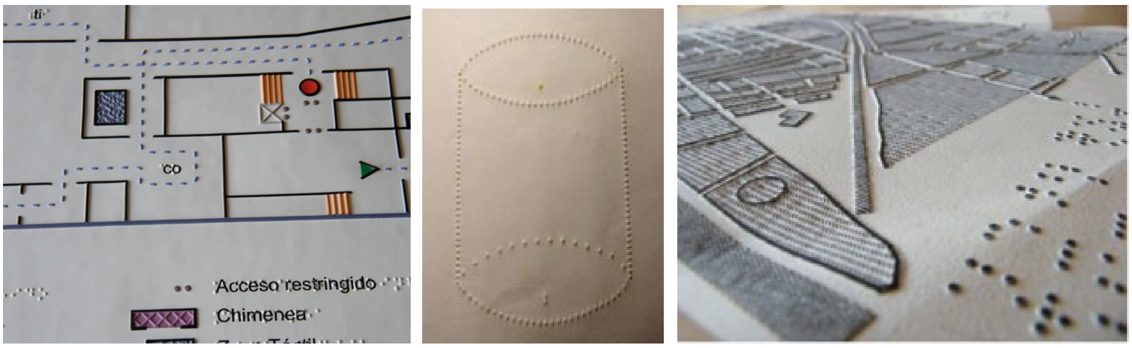
The manufacturing process used to obtain a TG depends on the material the TG is made of. In turn, the material used for a TG depends on the final use (fixed or portable). In the case of portable TG, the material used will also depend on whether the TG will have an indoor or outdoor location. Edman [1] proposes more than a dozen of methods for both types of TG altogether. As a summary, the most common materials and processes used to obtain each type of TG are (more information in [1,2]):

- *Fixed Tactile Graphics*. Casting processes are typically used for bronze TG, whereas machining processes are more common when the TG is made of metals such as stainless steel or aluminium. Fixed TG are also made either from plastic sheets cut by machining and built on each other, or by a moulding process using a thermosetting resin. Finally, although not very often, some TG are manufactured manually using glazed and fired ceramic materials. Generally, the recommended size for fixed TG should not exceed 90x60 cm, as a larger TG will make haptic perception difficult. Figure 1 shows two fixed TG.
- *Portable Tactile Graphics*. Thermoformed thin thermoplastic sheets (0.1-0.2 mm) or paper-based techniques are used to manufacture portable TG. Two types of paper-based techniques are mainly used to obtain portable TG: embossed (paper stamping/drawing) and microencapsulation (paper with embedded microcapsules that swell when they contact the ink and after applying heat). Figure 2 shows the three types of portable TG.



a) b)

Figure 1. Fixed tactile graphics: **(a)** cast bronze; **(b)** plastic sheets cut by CNC machining and built on each other. [2].



a) b) c)

Figure 2. Portable tactile graphics: **(a)** thermoforming of thermoplastic sheets; **(b)** embossed; **(c)** microencapsulation. [2].

TG are usually produced in low quantities (generally a single piece production in the case of fixed TG), are of small size and include small reliefs. For these reasons, Additive Manufacturing (AM), both the direct method (RM: Rapid Manufacturing) and the indirect method (RT: Rapid Tooling), seems to be a very interesting option to manufacture TG. In this work, a literature review related to the application of AM techniques to obtain tactile graphics, both directly and indirectly, is presented. According to the requirements to be fulfilled, the literature review proves the suitability of the application of AM techniques to manufacture TG. Then, a new technique, currently under development, to obtain TG is proposed. The technique is based on the application of the principles of AM to obtain ceramic tactile graphics by deposition of glaze to shape the relief on a ceramic tile.

Following, the list of abbreviations used in this paper to refer to the different AM techniques:

- SLA: Stereolithography.
- PBP: Powder-Binder Printing (also called 3DP).
- SLS: Selective Laser Sintering.
- FDM: Fused Deposition Modelling.
- PJM: PolyJet Modelling (injected resin and cured by UV light).

2. Application of Rapid Manufacturing techniques to obtain tactile graphics

Rapid Manufacturing is a production strategy to obtain end-use parts directly or indirectly from a rapid prototyping technology [3]. RM enables the manufacture of parts directly from a digital product definition and without the need of machining, casting or forming processes. RM employs AM techniques and it is especially suitable for single piece production or very short production runs, where the value of the tooling could not be amortized. The application of RM based on AM techniques is very appropriate to manufacture TG, particularly for the fixed ones.

Many studies about the application of AM techniques to obtain TG (by using different AM technologies) in one step can be found in the literature. 3D models with significant heights (physical models) have been made for haptic exploration in teaching applications. Orientation TG (heights of low reliefs) have been developed to include Braille, graphics and textures. New types of symbols, difficult to obtain using other techniques, have also been realised, and material and deposition techniques have been developed. In most cases, the resulting products are validated by a haptic exploration from a visual impaired user.

Skawinski et al. [4] presented one of the first applications. The researchers used SLA to reproduce chemical molecules in 3D as a tactile resource for teaching purposes.

In the field of tactile models, [5] and [6] reproduced architectural environments using PBP and SLS respectively.

Voženílek *et al.* [7] used TG obtained by PBP with students from primary and secondary schools. The aim of the work was to analyse if the spatial understanding of visually impaired people could be improved. They also studied whether there is a reduction of anxiety or fear when visually impaired people have to face unknown environments. It was concluded that Rapid Prototyping techniques were able to make maps and tactile models and, furthermore, they could include a certain level of detail depending on the particular needs.

In order to obtain fixed TG for indoor orientation (tactile floor maps) by AM, Urbas *et al.* [8] analyse the use of FDM technique with ABS in various colours, with a subsequent post-processing to reduce roughness. The application for indoor orientation in a museum showed very satisfactory results, with the exception of Braille and Latin alphabet.

The use of AM techniques to manufacture TG allows the incorporation of new volumetric symbols and 3D icons, in addition to the usual low-rise reliefs (Braille, lines, textures, etc.), improving interpretation. Gual *et al.* [9,10] developed new volumetric symbols (vertical cylinders, pyramids, cones, spheres, inverted cones, etc.) with heights of up to 20 mm. The TG manufactured with these symbols were obtained using PBP. The results concluded that the use of these 3D symbols clearly improves the location of the user on the map. However, it is not advisable to incorporate more than six different symbols, as to prevent recognition difficulties. Holloway *et al.* [11] conducted a similar research. In this case, researchers used FDM to obtain TG with volumetric symbols and concluded that the majority of users preferred this type of TG.

In [12], McCallum *et al.* developed an equipment to generate TG on different substrates using photo-polymerizable resins sprayed by a multi-nozzle piezoelectric head. They defined all the variables that have an impact on the desired reliefs. The technique used is similar to Ink Jet Printing, and it has not had any subsequent development.

Regarding the development of new processes, Zhang *et al.* [13] studied the generation of Braille code using clay suspensions (ceramic ink) and a refillable electromagnetic print-head. The tests were carried out on wet tile surfaces and partially dried surfaces, testing with different compositions of the ceramic ink. Unlike the case of wet tile surfaces, results were satisfactory for partially dried surfaces with a ceramic ink with a higher clay content (20-25%). However, further work in this direction is required to improve the process.

Finally, it is worth mentioning the research work conducted by Voženílek *et al.* [14], who presented a review of the state of the art of printing Braille for packaging applications using UV ink-jet printers. Although the application of this technique to manufacture TG has not been addressed, the research is of great interest since it allows the investigation of the advances in the use of UV ink-jet printers to obtain text and graphics in relief.

3. Application of Rapid Tooling techniques to obtain tactile graphics

Rapid Tooling is a production strategy that employs specific techniques to obtain tooling (moulds, dies, fixtures, etc.) in a shorter period of time and at a lower cost than if conventional techniques were used. RT particularly focuses on short or very short production runs, although some techniques may also be suitable for medium production runs (resin casting, plastic injection, thermoforming, pattern for sand casting, etc.). In general, a RT technique is said to be used when an AM technique is employed to obtain the tooling, either by direct methods (direct tooling: tooling is constructed by the AM system) or by indirect methods (indirect tooling: tooling is constructed from a pattern generated by the AM system) [3].

In the case of fixed TG, RT seems not to be very appropriate, since single pieces are usually produced, and it would only be of advantage for bronze cast and resin casting. This fact is proved by the lack of evidence in literature in the application of RT to fixed TG.

However, in the case of portable TG obtained by thermoforming of thermoplastic sheets, RT does prove to be very interesting, since production runs usually range from some dozens to some hundreds of parts. The thermoforming moulds do not require tight tolerances, the loads to be carried are small (sheets of 0.2-0.5 mm thickness) and wear is low. For these reasons, metal moulds are not required. The need of metal moulds will significantly limit the amount of AM techniques that could be used. Additionally, AM techniques are much more expensive when applied to metals.

The results of the literature research reveal the above-mentioned conclusions, as AM techniques do not employ metals when applied to obtain tooling for thermoforming of short production runs. In particular, the techniques typically used are FDM and PBP, and, to a lesser extent, SLA, due to its high cost.

Zhang *et al.* [15] presented the first application of RT techniques to obtain moulds to thermoform TG. SLA was used to manufacture a mould for thermoforming the parts of a human heart for haptic exploration. Researchers showed that this technique is perfectly feasible and has a slightly lower cost than if the required mould is machined. However, at that moment the cost of manufacturing SLA parts was very expensive.

The most remarkable work related to TG to assist urban mobility was carried out by Serrano *et al.* [16]. In this work, the authors use two AM techniques: PBP without post processing, and FDM using low-cost equipment, PLA and a 0.5 mm nozzle. The two techniques are used to obtain small moulds that include: Braille characters, lines, textures and other higher symbols. All these characteristics are measured in both moulds. Later, 0.2 mm plastic sheets are thermoformed using the mould obtained by

PBP and the same characteristics are measured. As a conclusion, the production of small batches of TG using both AM techniques is feasible, especially when using PBP. Figure 3 shows both moulds and a thermoformed part. Nevertheless, in the case of FDM, the use of a nozzle with a smaller diameter (e.g., 0.3 mm) and a better control of process parameters should result in better outcomes. Mould durability could increase as explained in [17], where the use of FDM to obtain thermoforming moulds is analysed. In this work, a Stratasys specific material is used and more than 500 duplicates with PET and HIPS 0.3 mm sheets are achieved.

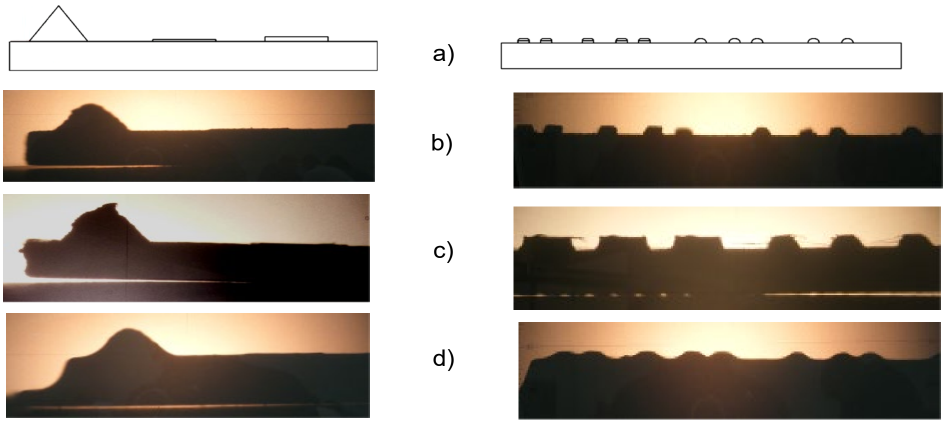


Figure 3. Thermoforming of TG: **(a)** patterns; **(b)** mould constructed by PBP; **(c)** mould constructed by FDM; **(c)** thermoforming sheet using (b). [16].

Previous research has addressed the use of AM techniques for RT in thermoforming manufacturing processes and short runs. In the health field, two interesting investigations show the application of RT to obtain thermoforming tools for medical prostheses using non-metallic materials. The work presents an in-depth study about the feasibility of RT for single piece or very short production runs. To the author's understanding, these RT parts have some similarity to the TG (small reliefs, small thickness, etc.), thus, the conclusions of the work can provide valuable insights for the application in TG.

Jiménez *et al.* [17] examined the possibility of manufacturing occlusal splints using thermoforming. The study was carried out by comparing the tooling obtained by different AM techniques: SLA, SLS, PJM, PBP and FDM. Furthermore, the comparison is completed adding the milling process as a benchmark. Researchers concluded that all cases are perfectly feasible, and that the best relationship cost-quality is for the tooling manufactured by PJM and FDM.

Chimento *et al.* [18] obtained tooling for thermoforming of medical devices such as prosthetic sockets and orthotic interfaces. The moulds for these parts are traditionally made with plaster, so the authors used PBP, since the material employed has similar characteristics. They carried out tests with two different materials and different post processing operations (none, and infiltrated with epoxy, cyanoacrylate, water, etc.). The work concluded that the process was proved to be feasible and that the best combination is either not to carry out any post processing, or infiltration with acetone:cyanoacrylate (4:1). In this way, the porosity of the parts obtained by PBP, a property that increases thermoforming performance, is partially maintained.

4. Tactile graphics on ceramic tiles by deposition of glaze

As mentioned in Section 1, fixed TG require high durability and strength, as they are usually located in public spaces. To be inclusive, i.e., to be useful both for people without and for people with total visual impairment, fixed TG should include elements in relief (texts in Braille, textures and other graphics) together with plain text and should be supported by the use of colours.

Fixed TG must also be resistant to wear, tear, and cleaning products. Furthermore, fixed TG located outdoors need to withstand changes in temperature, UV light radiation, rain, and dirt, as well as being able to be cleaned with more aggressive techniques than those located indoors. Materials used for fixed TG must meet all these requirements. Corrosion resistant metals are used for metallic fixed TG. However, they lack the possibility of polychromy, so the incorporation of plain text must be done in relief or painted. In addition, fixed metal TG require expensive manufacturing processes. Fixed TG made of plastic materials are less durable due to the effect of UV light in outdoors applications, but they can incorporate polychromy to some degree, depending on the technology used. Interested readers can find a comparison between the different types of TG according to the material in [2].

A few years ago, a new type of TG, called "Kersigns", was developed [2]. The TG is made on a ceramic base and the reliefs are created by deposition of glaze. Due to the high performance of ceramic materials, this type of TG fully satisfies all the above-mentioned requirements, including plain text and polychromy. In addition, the manufacturing cost is much lower than in the case of other materials. Figure 4 shows an example of this type of TG. In Table 1, permanent TG obtained by different manufacturing processes are compared according to the degree of fulfilment of some of the main requirements.

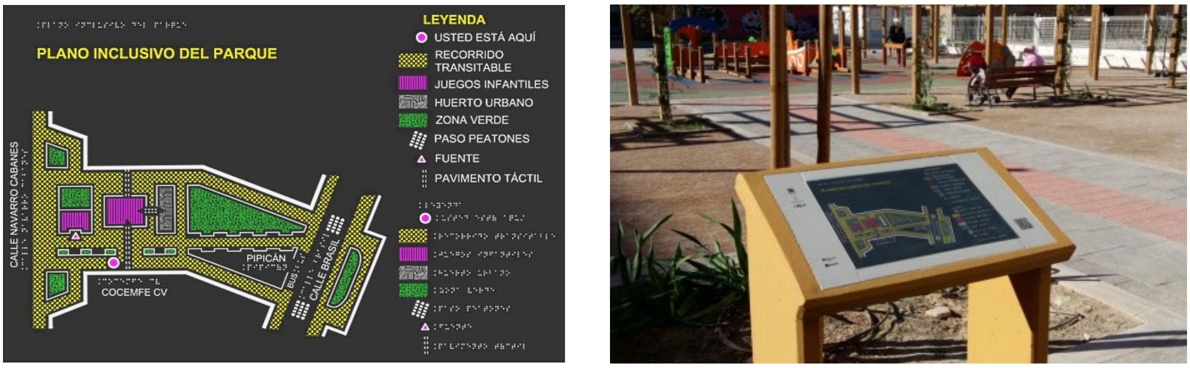


Figure 4. A first implementation of the Kersings product installed in a park, showing the TG and its assembly on a reinforced concrete base [2].

Table 1. Degree of fulfilment of the main requirements for outdoor applications using permanent TG obtained by different manufacturing processes (adapted from [2]).

	Mechanical and wear resistance	Resistant polychromy[a]	Several ranges of relief heights	Resistance to weather condit.	Chemical resistance[b]
Bronze casting	↑↑	↓↓	↑↑	↑	↓
Aluminium machining	↑	↓↓	↑↑	↑	↓↓
Polymers	↓↓	↓↓	↑↑	↓↓	↑
Glaze deposition on tile	↑↑	↑↑	↓↓	↑↑	↑↑

[a]In metallic materials, polychromy is obtained by thermosetting polymeric paints, which are sensitive to UV radiation in the medium term.
[b]Machined aluminium is very sensitive to acids and bases, unless a protective coating is applied.

An unpolished single colour tile made of porcelain stoneware is used to manufacture this type of TG. The text and flat graphics are printed on the surface by deposition of glaze (in different colours according to the required polychromy) to create the reliefs. Later, the tile goes through a firing operation to consolidate the inks and glazes. Ceramic glazes are concentrated suspensions with a content of solids (around 70% in weight and mainly based on vitreous material (80-95%)), small additions of clay materials and other additives besides mineral pigments.

The glaze reliefs are obtained by silk-screen printing techniques. Since the glaze is deposited in layers, different silk-screens are required depending on the relief to be generated in each layer and the colour of the glaze to be used. Due to the rheological characteristics of glazes, which are different at room temperature or during the firing process, specific glaze compositions and application techniques were required. Using existing techniques, the heights of the reliefs may slightly exceed 0.5 mm, which is sufficient for most cases [1, 19]. The diversity of information that can be displayed is limited, and heights around 1.5 mm may also be required. Furthermore, if slight variations of the same TG are needed (e.g., change of the symbol "you are here"), additional silk-screens for each variant have to be generated.

The application of AM techniques as a strategy for RM to obtain the reliefs in this type of TG is considered a very suitable alternative. The main reasons are related to the manufacturing characteristics and to the production volume. The material is deposited by layers on a smooth and flat surface, different colours (different glaze compositions) are used, and a single or a few parts with slight variations between them are produced. The literature review presented in this work, which is part of an on-going research project, has established the following as the possible techniques for a layer-based application of glaze:

- Deposition of the glaze in liquid state using a single-nozzle head.
- Deposition by extrusion of molten thermoplastic filament with a high percentage of filler, so that the polymer volatilizes and the fillers are consolidated during firing.
- Deposition of the glaze using multi-nozzle heads by ink jet techniques, similar to a previously mentioned research [13].
- Use of PBP techniques with a light-curing resin binder deposited with a multi-nozzle head in a similar way to PJM. In this case, the glaze must be deposited in layers in solid state and in the form of small grains.

Currently, authors are working on the evaluation of the feasibility of these possible alternatives in order to select the most appropriate one and proceed with its development.

5. Conclusions

This work has shown the feasibility of using AM techniques to obtain TG and multiple applications have been presented. AM techniques are especially suitable, as TG are usually manufactured in short runs and must be flexible for design changes. The use of RT strategies based on low-cost technologies (FDM and PBP) to obtain moulds for thermoforming portables TG has been proven to be perfectly feasible. In this case, manufacturing costs are much lower than when conventional tooling is used.

However, the applications for fixed TG carried out to date are very limited and mainly focused on obtaining TG in polymeric materials using PJM and FDM techniques. Fixed TG are also obtained by PBP, since this technique can produce polychromic planes although not very resistant. In both cases, the products obtained have limitations in terms of high durability. The application of ink jet techniques with deposition of suspended ceramic has also been studied, but no further development has been conducted due to the many limitations found. Although the use of other techniques and metallic materials could fulfil the high durability requirements, such techniques have not been addressed. The main reasons for this are the high cost and the deficient surface finish, too rough for the sense of touch and inappropriate due to the accumulation of dirt.

The new type of TG based on the deposition of glaze on a ceramic tile fully meets all the fixed TG requirements, except of the relief height that can be achieved. Furthermore, this new type of TG has a much lower cost and significant advantages for outdoor applications. However, the deposition of glaze using silk-screen printing techniques has the relief height limitations mentioned, and long cycle times are required. For this reason, the development of a layered deposition technique based on AM is considered a preferential line of work for the authors.

Acknowledgements

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