Examining approaches to personalized 3D printed wheelchair cushions

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ABSTRACT

Wheelchair users are a greatly varied population group for which no single product can offer a consistent level of comfort. When designing cushions for pressure relief, unique factors like a user's weight, posture, susceptibility to pressure sores, as well as other compounding conditions all call for a custom product. Unfortunately, existing custom solutions can be financially inaccessible and time-consuming to manufacture, especially in a public healthcare setting. 3D printing, which to a small extent, is already used for wheelchair cushions, can also be used to personalize them, to achieve better pressure distribution. Here, we discuss three approaches that allow users to design and print their own cushion, why that is important, and what advancements in the field will further reduce the barrier to easily achieving great results.

CCS CONCEPTS

• **Human-centered computing → Accessibility technologies**; **Accessibility design and evaluation methods**.

KEYWORDS

assistive technology, 3D printing, comfort

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1 INTRODUCTION

Wheelchair users often need to spend long times in their chair throughout the day, either due to work or leisure activities. One study estimates daily use time of manual wheelchair users at an average of 10.6 hours per day [22].

Minimizing wheelchair seating discomfort is a major concern in a wheelchair user's daily life. Particularly pertaining to pressure, the risk of pressure ulcers is crucial as they are difficult and costly to treat [11, 16, 17]. Pressure ulcers are a skin wound that can appear as a slight discoloration if mild, or a deep wound exposing muscle and bone at its worst. These ulcers can be formed as pressure is applied to the skin over a period of time — the greater the amount of pressure or the duration of time, the bigger the risk. Additionally, the friction on the skin and the shear forces between bones and the external surface can raise the risk substantially. These ulcers are important to prevent as beyond the discomfort, they can be very dangerous to elderly population in care homes [3, 4]. To relieve the built up pressure, wheelchair users are advised to shift their weight around in regular time intervals and even transfer out of their wheelchair when possible. However, the latter is not practical for wheelchair users at work, school, or outdoor settings.

This paper investigates how 3D printing technologies can be used to create accessible, affordable, and personalized cushion designs. Many current approaches to custom wheelchair seating, like plaster molding, require the user's presence in a lab setting, are time-consuming, and often produce one-off molds that are then discarded [18]. 3D printing is a promising alternative — its additive nature means that it creates no waste, and being a digital process, it can be assessed and edited with minimal manual labor and waste.

2 BACKGROUND

3D printing is now far from a new technology as it has had various applications in the medical field [5, 15]. It is also becoming increasingly ubiquitous, with more schools, universities, maker spaces and hobbyists owning a machine, which has brought their price and that of their materials down. The prevalence of 3D printers globally also means that they are more geographically accessible, reducing the need for expensive imported devices, especially when a personalized solution might require adjustments [9].

When considering solutions for custom, 3D printed cushions, we focused on approaches that would align with the open-source maker movement ethos, as seen in the RepRap movement [14]. It is our belief that solutions should be inclusive and approachable by all AT users, so this project relied on software that is free and likely to remain free, as well as open-source code. CAD skills are often associated with 3D printing, which is why we provide approaches that either do not require them or include them in a minimal, straightforward capacity. This is beneficial for individual users but clinical settings as well, as most teams do not include CAD specialists [19]. In this way, we hope to open up access to as many disabled people as possible, following an essential principle of disability interaction design [12].

2.1 Existing solutions

Several existing products aim to assist users in managing their comfort. Many cushions are specifically designed to distribute pressure more evenly throughout the seat pan and alleviate localized peaks of high pressure. Products have used different methods for pressure distribution and comfort: some have used segmented pockets of

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fluid (air or gel), while others rely on specific geometry and varying elasticity within their product [2].

Beyond the great host of cushions, some products attempt to actively shift the user weight using air bladders within the cushions [7, 21] or built-in mechanisms that move parts of the chair to change the posture (e.g. Permobil powered chairs). Embedded activity trackers in the seat can also allow users to offload the mental load of remembering to shift their weight [1, 13]. However, active approaches such as these are usually not preferred by manual wheelchair users as the batteries add significant weight.

Contoured cushions can also help distribute pressure and lead to a greater perceived sense of comfort [8]. W While effective, this solution can be bulky or more noticeable, potentially increasing the social barrier to using this technology due to social stigmas [6]. 3D printing can reduce the cushions' volume, while still achieving varying degrees of stiffness and distributing pressure.

3 THREE METHODS, ALL FREE

In this section we describe the work carried out to either develop or prepare for three different approaches. We consider how a pressure map, in other words a grid of pressure values, can be used to alter the density of the 3D printed cushions based on the part's infill percemtage and type. Infill percentage, a term common in 3D printing, refers to the volume of the printed part that is filled with plastic and a higher percentage of infill results in a stronger, stiffer part [20]. Infill is usually structured as a lattice and a different infill type means a different lattice, with varying mechanical properties. To alleviate localized points of high pressure, we reduce infill in that area and increase it elsewhere so the load is more evenly distributed.

3.1 GCODE generation

The usual process for 3D printing a part involves designing in 3D CAD (e.g. Fusion 360) or 3D modeling (e.g. Blender) software, importing the .STL file in slicer software and producing GCODE commands for the 3D printer. However, FullControl, a Python-based library by Gleadall et al., enables the creation of 3D structures using GCODE directly [10]. With this library, we developed a script that generates cushion designs out of a honeycomb lattice.

The script is hosted online and its parameters can be customized through a simple web form. Users can specify dimensions depending on the size of their wheelchair, as well as upload a pressure map file so that the density of the cushion is personalized to their unique needs. By directly implementing flow rate change GCODE commands (M221) with the FullControl library, we can achieve fine-tuned pressure adjustment. To account for the empty space inherent in a lattice structure, we are generating unit blocks with consistent paths that, with the same flow rate, result in repeatable material deposition (Figure 1). This way, determining the pressure characteristics of a single unit of the honeycomb lattice is representative of the whole cushion structure. Lastly, the user can generate contouring around the seat pan for support (but not pressure distribution) and a thigh divider.

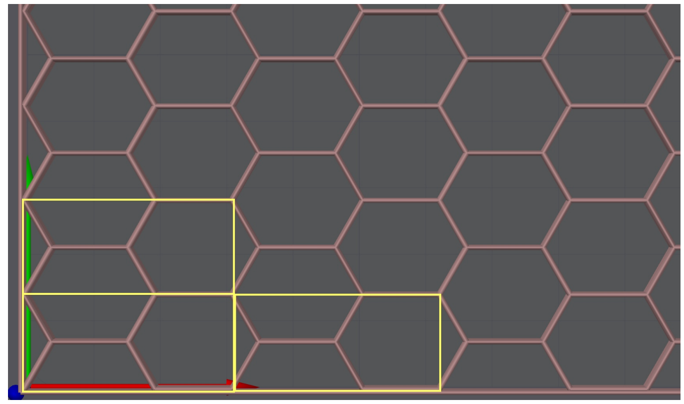

Figure 1: Top view of GCODE generated honeycomb lattice assessed in a slicer. Yellow rectangles indicate the unit cells that are repeated throughout the structure.

3.2 GCODE post-processing

The second approach follows the standard 3D printing process: the cushion model is imported into the slicer, and sliced into GCODE with the desired settings (e.g. the cushion's base density determined through the infill type and percentage). The personalization comes through a post-processing script that parses the GCODE file and tracks toolhead movements through G0 and G1 commands — the former refer to linear moves and the latter consist of a linear move while extruding plastic.

The density of the cushion can be changed locally by adjusting the amount of plastic deposited by each G1 command. By overlaying the grid of the pressure map on top of the print geometry and breaking up long G1 moves into smaller ones that fit within each grid's cell, we can alter density on the cell level. The post-processing script then assigns relevant M221 commands (flow rate adjustments) before each G1 move.

3.3 SVG modifiers

Our third approach to producing personalized cushions is not that radical, but we believe it has merit as it is simple to execute and eliminates the need for a pressure map (and the expense and time commitment involved in procuring one). Here, we still import a 3D model in the slicer, but unlike the post processing approach, all modifications happen before it is sliced into GCODE.

Modern slicers (e.g. Cura or Slic3r derivatives like Prusaslicer, all of which are available for free) have a feature known as "modifier geometry." Modifier geometry involves adding base shapes (boxes, spheres, and cylinders) into the workspace and altering features of our model (in this case, the wheelchair cushion) where the two overlap. Update 2.7.0 of Prusaslicer introduced SVG support and with it, SVG modifiers. This works by creating an object of variable thickness out of the non-transparent part of an SVG image.

Here, we propose stacking SVG modifiers to mimic a discrete pressure map. Slicers treat parts and modifiers in hierarchical order, so in the list of all objects, the SVG modifiers must be ordered from largest to smallest to prevent larger SVG objects from overwriting the effects of the smaller ones. We drew the different regions of pressure in Inkscape, with a transparent background, and exported each separately as an SVG file as seen in Figure 2.

Figure 2: Stacked SVGs drawn to look like a pressure map on the left and an exploded view of the stack on the right

3.4 Printing the cushions

The generated GCODE from each of these methods can be viewed on any modern slicer (Fig **??**) and assessed to ensure compatibility. It can then be printed on any FDM 3D printer suitable for TPU/TPE printing (40D or 85A shore hardness is recommended). The online user guides will provide information to help users identify whether their machines (or that of their nearest maker space) are suitable and that includes machine characteristics (e.g. specifications of the extruder) and slicer settings (Fig **??**).

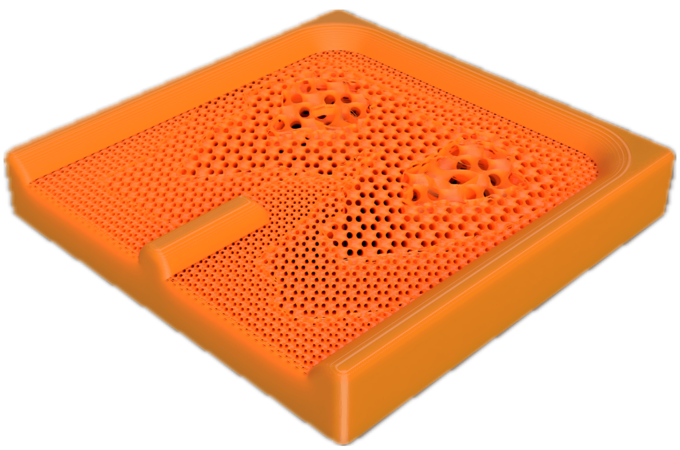

Figure 3: Render of generated GCODE Right: Printing the GCODE with 40D TPU

4 IF YOU HAD TO PICK ONE

Designing personalized cushions for 3D printing is achievable and we have described three methods that can easily be repeated by users, with as low barriers of entry as possible. Users can choose between:

- the GCODE generation approach, which takes the user's needs and creates the GCODE file directly;
- the GCODE post-processing approach, which modifies the slicer-generated GCODE for a generic cushion and personalizes it according to a pressure map; or
- an in-slicer approach that uses a stack of SVG images as infill modifiers to replicate different regions of a pressure map.

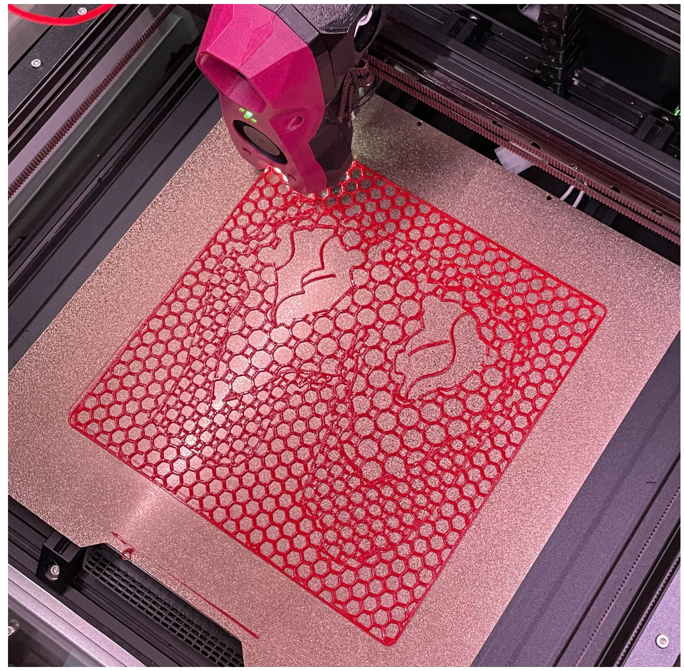

Figure 4: Printing a scaled down cushion with the SVG approach using 40D TPU on a Voron FDM 3D printer

None of the methods is inherently better than the others. We will examine their advantages, disadvantages, determine the context they are each best used for and discuss what further research and development is needed to progress each of them. Firstly, let us consider the need to use slicer software and its implications. As explained, the GCODE generation method is distinctly different by virtue of not needing a modeling or slicing software, and we believe this to be its most important attribute. By not relying on modeling software, it is already simpler for users, as it poses fewer obstacles. By not needing slicing software, this approach is not reliant on slicers behaving the same way for years to come. A slicer update affecting how it generates perimeter or infill paths might result in changes in how pressure is distributed and this unpredictability, especially if a software update does not prominently mention this, can quietly change the cushion's characteristics and pose additional challenges for users. Additionally, a slicer is only concerned with even distribution of material at a set infill percentage. However, consider an even pressure grid of 32 x 32 data points; we want to ensure that down to the scale of each grid cell we have even material deposition for even load distribution. In this sense, the GCODE generation approach allows for this finer control as it designs the unit cells based on the cushion and pressure map size. In the user journey of a slicer-dependent approach, the most crucial point is the user obtaining the correct cushion model. Even a straightforward, guided usage of a CAD program, such as adapting a parametric model to the user's needs, can pose difficulties that discourage novice makers. As such, developing a solution that takes the CAD or 3D modeling software out of the process can raise the retention rate of users. Conversely, the methods that use slicers already benefit from a lot of 'quality of life' features that the GCODE generation method does not have access to. The ability to divide objects for print on smaller printers, along with a way to join them (as seen in Prusaslicer) is more inclusive for people whose wheelchair seat pans are larger than their (hobbyist-level) 3D printers. This is not to say the GCODE generation method will never have access to this; it is in fact, already in development, but it is one of several features that have to be purpose-built. Similarly, slicer-dependent methods have access to a wide range of infill types, and while many are not great at distributing the load, there are currently more options than for the GCODE generation one. Further work on the latter will focus on generating a variety of load-bearing lattice unit cells for better performance. Much of the work needed for any of these methods to be adopted is external to their individual development. While using a pressure map can yield great personalisation, the equipment itself is prohibitively expensive for the average user. While the mapping procedure can take place in a clinic with an occupational therapist, this is not always feasible. We suggest that these tools are accompanied with a library of pressure maps or SVG stacks that other users can implement or use as a base they can modify.

These methods can certainly improve even further, but at their current state appeal to unique sets of users. Those with access to large-scale 3D printers that can fit whole cushions within their build plate, can look to the GCODE generation approach or the SVG stacking method. The choice will largely depend on whether they can obtain a pressure map or not. If yes, then GCODE generation will suit their needs, but if not they can experiment with SVG modifiers in the slicer until they get satisfactory densities. If, however, users do not have access to large format 3D printers, they would be best served by the slicer-dependent options, which would allow them to cut up the model in smaller parts and join them later on.

5 CONCLUSION

While 3D printing is not the only valid approach to developing cushions, it has tremendous potential to make a social impact by involving AT users in the design and development of open-source solutions, just as the RepRap movement brought about significant changes to 3D printing itself. These methods still need further development and user testing with AT users of varied making abilities, but we believe they represent a positive step toward empowering wheelchair users and hobbyist makers to come together and develop meaningful, inclusive solutions.

In the spirit of the maker movement, we will be uploading all our code on https://github.com/andreaspolydorides/OpenCushion and we encourage AT users, makers, and coders to engage with us on these solutions and work with us to improve them.

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