EXPLORING 3D MODELLING SOFTWARE AND PROTOTYPING WITH PPE AND TEXTILE DESIGNERS

Andrej Cupar*
University of Maribor, Faculty of Mechanical Engineering, Slovenia
andrej.cupar@um.si

Katherine Townsend
Nottingham Trent University, School of Art and Design, United Kingdom
katherine.townsend@ntu.ac.uk

Sonja Šterman
University of Maribor, Faculty of Mechanical Engineering, Slovenia
sonja.sterman@um.si

ABSTRACT

The use of 3D CAD software is expanding in various fields, but the thing they have in common is a virtual 3D model. In this paper we will discuss 3D modelling using three different techniques applied in two research projects. First, we focus on parametric 3D modelling used widely for industrial products, second, we briefly discuss modelling using freeform surfaces, and third, 3D models defined with a spatial triangulated mesh.
The aim of the first research project, ‘Redesigning PPE Gowns’, funded by the Arts and Humanities Research Council (AHRC) in the UK, was to enhance the design of reusable, personal protective equipment (PPE) as worn by healthcare workers to treat patients with coronavirus. All existing gown details were modified, including the cuffs, where a solution was identified to reduce cross-contamination with a doffing hook, to make it easier to remove the gown safely. The doffing prototype was developed using CAD software Rhinoceros 3D and SolidWorks and its design based on the shape of a flower, each petal providing a potential hook. In the second project ‘OptimTex - Software Tools for Textile Creatives’, research was performed to improve textile software knowledge and skills for students in higher education. The investigation enabled the students to experiment with virtual 3D prototyping and 3D mesh processing.

Keywords: 3D software, prototyping, doffing hook, virtual modelling, PPE, 3D textile design

INTRODUCTION

3D CAD (Computer Aided Design) software operates with virtual 3D models and is used in various fields. According to licence providers there are two main types, proprietary and FOSS (Free and Open-Source Software) (Snyk Limited, 2022). Some uses of FOSS in the field of 3D CAD will be highlighted in this paper. Free software often has limited software features and other user-oriented functionality but can be a good replacement for expensive packages. 3D CAD software helps students to understand how manipulating concepts using CAD and virtual reality can inform analogue material practice and experimentation (Nimkulrat N., 2020).

In the project ‘OptimTex - Software Tools for Textile Creatives’ photogrammetric 3D human scanning was deployed to support virtual pattern developments. OptimTex is a project to collect and build knowledge base from different fields to support young creative textiles. With our partners, several knowledge fields were covered, our was to 3D scan human body and to repair and re-model 3D mesh for further garment patterns creation in CAD/PDS (Pattern Design Software) (Cupar A., et al., 2019).
In the project ‘Redesigning PPE Gowns’ we applied 3D CAD within the field of 3D industrial design to extend product use and safety.

So, both projects share a fusion of textile, engineering, industrial design, photogrammetry, and digital visualisation towards creating ergonomic designs to support users.
Research for the project "Redesigning PPE: enhancing the comfort and safety of healthcare workers wearing isolation gowns to treat patients with COVID -19" (AHRC/ UKRI, 2021) was developed to answer the engineering question, "What new materials, design, and manufacturing approaches should we start to consider in preparation for pandemics, e.g. reusable PPE to replace single use?" (UKRI, 2020). In reviewing the literature on PPE for healthcare workers and the results of a survey of nurses from the NHS (National Health Service) (Šterman S., et al., 2022), we obtained a great deal of detailed information about the problems they faced, particularly when wearing one-size disposable garments. Based on this information, we designed reusable protective gown prototypes (Townsend K., et al, 2022). In addition to the problem of gown size, we addressed other issues associated with one-size-fits-all, such as sleeve/gown-length, cuff, neck and waist fastenings and difficulties in putting on (donning) and taking off (doffing) the gown without spreading coronavirus. In this article, we present some of the potential solutions for redesigning the sleeve cuff, and how this initiated the development of a doffing hook, created using 3D modelling which can assist with the safe removal of the protective clothing.
Fashion and textile designers have been experimenting with emerging technology since the 1990s, to integrate 2D surfaces and 3D concepts with the human body (Townsend K., Goulding R, 2010; Townsend K., et al. 2020). Consequently, hybrid approaches to hand and digital craft are part of most designers' methodologies. However, proprietary 3D software remains costly and often encompasses standardized tool sets embedded within it that can undermine the creative autonomy of the designer leading to uniformity (Taylor J., Townsend, K., 2014). By using a mix of proprietary and FOSS in both the Redesigning PPE (Doffing Hook) and OptimTex projects the designers were able to explore 3D CAD from an open perspective.

METHODS

This practice-oriented study responds to the identified need for research into the design of reusable PPE (isolation gowns) and the area of 3D modelling. The first step was a literature review of both fields to expose areas that could be interconnected. We identified a solution for a problem of doffing PPE gowns with a hook. The prototype was made using the FDM 3D printing method. Another practice-oriented study involves 3D scanning of a human body with 3D photogrammetry and to repair and re-model 3D mesh using 3D modelling tools. Presented are two projects where multiple research fields were involved, mostly exposed 3D modelling, to serve as complementary approach.

RESEARCH AND DESIGN OF PPE GOWNS

Gowns are primary garments intended as uniforms for workers in various occupations, providing protection at work. This requirement could be met effectively if the sizes and materials were always adapted to the needs of the users and working conditions (Townsend K., et al., 2022).
Unfortunately, problems with the wearing of gowns have been identified on several levels. First, the literature review (Wong H., 2022) evidenced many examples where PPE, especially gowns, interfere with day-to-day working practices. This fact was also confirmed by interviews with clinical and nursing leads and wearers in various hospitals in the United Kingdom, where the survey was conducted in the first stage of the research in "Redesign of PPE Gowns" (Šterman S., et al., 2022). The review of 30 disposable and reusable gowns also confirmed the problems with sizes, patterns and materials used.

Findings from empirical research into gown design and use enabled us to identify critical elements that could improve users' experiences with PPE. Since reusable gowns are a more sustainable solution than disposable gowns, we have developed a reusable gown system incorporating multiple sizes to accommodate different body types and postures involved in nursing patients with Covid. Medical gowns play an important role in protecting the health care system from the transmission of microorganisms and body fluids (Vozzola E. et al., 2018). The protection of the body is crucial for nurses' safety both during work and after work, when doffing.

Issues relating to donning and doffing gowns were reiterated in our survey alongside other issues relating to the design of the PPE gown (Nottingham Trent University, 2021). In this article we focus on cuffs, sleeves, and doffing. The most requested design option for a cuff was for a thumb loop. Most of respondents thought the sleeves are too long. Regarding the question: is your gown easy to put on and take off? Respondents' experiences varied widely depending on the type of gown they wore, how experienced they are, and how much time they have, to put it on and take it off. For these reasons we considered an extended cuff with several details. First, a cuff with a loop only (see also Figure 1-left), second, a cuff with a strap in different positions (see also Figure 1-middle) that can be hung on the innovative doffing hook and variation of the cuff (see also Figure 1-right).

Figure 1: An extended cuff with a loop (left), prolonged cuff with different positions of a strap (middle) and an extended cuff with two positions of the band, that would be used at the doffing hook (right)

Designing different 3D objects requires the application of different 3D modelling techniques. For our projects four types are applicable: 3D point cloud, 3D mesh, 3D surface model, and 3D volume model. In project 'OptimTex' for the capture of 3D objects and their representation, 3D point cloud and 3D mesh were used. Both virtual object types consist of a huge amount of data that describes real objects, involving 3D mesh editing and modelling. Scanned 3D meshes usually have holes and other errors which must be repaired to enable further use of a mesh.

On the other hand, in designing the doffing hook for 'Redesigning PPE Gowns', both surface and volume models were used along with the corresponding modelling techniques of: Parametric solid 3D modelling, NURBS modelling (Wikipedia, 2022; Farin G. E., Hansford D., 2000), and SubD modelling.

Parametric solid 3D modelling
Parametric solid 3D modelling is widely used in the product design industry. Speculative models with sketches and other features are compounded to build the final 3D model. Changes are possible with parameter adjustments. For parametric solid modelling of Flower hook and Pipe hook we chose SolidWorks although it is not a FOSS (Solidworks help, 2022; Vukašinović N., Duhovnik J., 2019).

Subdivision 3D surface modelling
Subdivision (or also SubD) is type of more "soft" modelling. Subdivision surfaces can be reshaped by modifying control objects which can be also added to create more detailed part of model. Modifying control objects means moving, rotating, or scaling three types of objects: points, edges, or faces. The final 3D model is usually a freeform object, often with a shape rarely or even impossible to achieve with parametric solid modelling. Continuity between neighbouring surfaces is assured, therefore beautiful shape transitions can be achieved (Kanaya Y., et al., 2007). 3D modelling of the Beast hook was performed in Rhinoceros 3D version 7 (Rhinoceros, 2004; Subdivision Surface Modeling, 2004).

Mesh modelling
Mesh modelling can be also performed with subdivision, but the larger number of spatial points involved, the harder it becomes to control. The modelling technique is like SubD modelling, but the final result is a mesh where continuity between neighbouring faces is difficult to control. For our project 'OptimTex' only mesh editing and processing approaches for closing holes, smoothing, and refining transformation were performed (Wikipedia, Affine, 2022). For mesh modelling and repairing Blender and MeshLab were used.

3D OBJECT DIGITALISATION

For a bespoke approach to garment production, 3D body scanning, 3D modelling and the reconstruction of the scanned body as a kinematic avatar, present very useful and advanced tools. As partners, the project, 'OptimTex - Software tools for textile creatives' (E-learning, 2022) several software solutions for textile creatives were utilised by students, supported with practical examples. Most of software employed is freely available to download and our focus in this paper will be on 3D oriented solutions.
In this paper the software Meshroom (Meshroom, 2022) MeshLab (MeshLab, 2022), and Blender (Blender, 2022) are discussed, as they were used to perform several steps to generate 3D objects as starting point for further work. Detailed use of 3D software is shown on projects Moodle page, where students can attend courses from project (E-learning, 2022).

Step 1: taking series of pictures from different angles of an object
Any modern digital camera can be used, especially convenient is mobile phone camera. There are several rules and suggestion to take in account to get acceptable final result, collected in (Meshroom, 2022). Also, video can be used to obtain pictures from video. But still images assure better results.

Step 2: using pictures to obtain digitized virtual 3D object using 3D photogrammetry
In 'OptimTex', the free software for 3D reconstruction Meshroom was introduced to students. The software is a complex composition of many partial solutions for photogrammetry. The program functions like a pipeline, where each successfully completed step leads to another one. With inappropriate input images the whole procedure cannot be completed. Therefore, is very important to follow rules in Step 1. The first two steps involve: importing images into program, saving the project, and starting computing processing. The process takes some time, depending on the number of input images, their size and mostly on computing capacity. A successful finished project builds a MeshroomCache maps structure, stored on disk. In each map a result of partial steps can be found. The finished result, the 3D model with .OBJ extension is stored last, called Texturing. There are plenty of other software for obtaining 3D meshes from pictures, some FOSS, some proprietary, but based on user experience (Author 1) and simplicity, the Meshroom is a good solution.

Step 3: scale adjustment of an object
The virtually crafted 3D object needs scale adjustment for any further manipulation. It is a main step whereby a user is responsible for producing an accurate result. Physical dimensions must be measured on both a real object and virtual 3D object to obtain the correct scale. This step must be repeated several times to get an accurate measurement while virtual and physical sizes can be at odds in the early modelling stages. In project OptimTex, MeshLab was used for scale adjustment and 3D environment mesh removal to get clean and proper scaled object, in our case the human body. With 3D scanning, scaling is already part of calibration process.

DOFFING HOOK

Evolution and shape exploration was performed in Rhinoceros 3D v7. Finally, three types of hooks were chosen according to appearance, production possibility, and usability: Beast, Pipe and Flower. All three models were modelled in SolidWorks 2021.
The hooks are meant to be mounted on a wall with wall inserts and screws like for example any ordinary kitchen cabinet. It is important to be mounted stiff enough to hold an adults' weight. All variants have multiple protrusions slightly inversed to facilitate contact with the cuff loop of the protective garment. Variants Beast and Pipe can also serve as key, or other object holders.

Model 1 - Beast
First model has the most complex shape. Therefore, it was modelled completely in Rhinoceros 3D. Shape was designed using SubD tools, then basic cylinders were subtracted using the Boolean difference tool. The Beast Hook will be made of moulded aluminium or another metal that can be sterilised. Its appearance has aesthetic associations with a creature's head with horns, muzzle, and eyes. The two eyes represent two screws, holding the hook on the wall as shown in Figure 2 (see also Figure 2-left).

Model 2 – Pipe

Second model in Figure 2 (see also Figure 2-middle) was meant for simple production, cut from single piece of pipe with an added plate at the back. The shape was redrawn from a sketch in SolidWorks 3D. The Pipe Hook can also be made of moulded metal or a suitable alternative material. Its appearance can be associated with a hand, grabbing upwards. Four screws hold the hook on the wall.

Model 3 - Flower

Third model, in Figure 2 (see also Figure 2-right), was again redrawn in SolidWorks 3D. Basically the section sketch is revolved and removed space between petals in the following extrude tool. The Flower Hook can be moulded or can be produced with a turning and additional milling for petals. This hook is mounted with three screws on the wall.

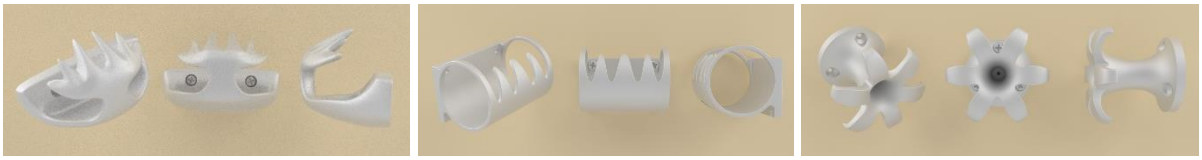

Figure 2: Beast hook (left), Pipe hook (middle) and Flower hook (right)

3D PRINTING

The manufacturing of virtual 3D objects can be performed using different techniques. From conventional material removal and welding to additive manufacturing (AM). For shape research and functionality testing an FDM (Fused Deposition Modelling) 3D printer was deployed due to accessibility, fast process, low price, and suitable material properties (Flynt, 2022). For 3D printing materials PLA (Polylactic Acid) and PETG (Polyethylene Terephthalate Glycol) were used (see also Figure 3-photos). Basically, the 3D shape is important to analyse at this stage, therefore envisaged material properties are not as important as the details and potentially functionality of a product. On the sketches (see also Figure 3-sketches) are shown new possibilities of using cuffs for easier doffing with a band on the outer side.

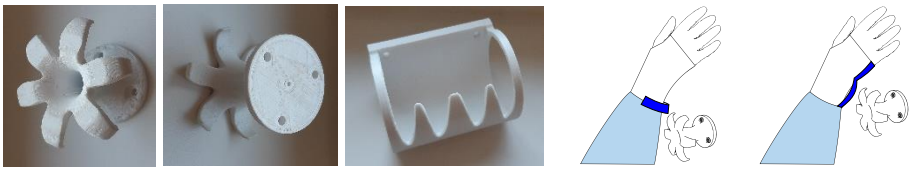

Figure 3: 3D printed Flower Hook (Photo 1 and 2) and Pipe Hook (Photo 3) and an extended cuff with different positions of the band, that could be used with the Flower Hook (sketches on the right)

TESTING

All three doffing hooks were mounted on a wall and tested for PPE removal. It was considered not to fully load the hook as FDM printers use plastic materials with lower stress than metal products. Testing the first generation of doffing hooks highlighted inappropriate design elements, such as the petals of the Flower Hook needing to curve more acutely, and the Beast Hook proving to be difficult to install due to limited access to the screw holes. Within Rhinoceros and SolidWorks, the models were modified, and 3D printed again. The modified shapes of the hooks were all appropriate for removing the PPE by the cuff loops. The next step is to manufacture hook prototypes from aluminium and include them in Gown Wearer Trials to test them in the healthcare working environment.

CONCLUSION

Each profession operates within the parameters of its field, using materials and technologies in physical, and increasingly virtual realms. This paper explores how interdisciplinary research can highlight and seek to solve human and environment centred problems using 3D modelling and prototyping. The two described projects are good examples of collaboration and cooperation across different fields. In the Redesigning PPE project, the hook design is used to add value to the gown, by protecting the wearer

against contamination from viruses, but this product could also be used by other professions that work with toxic substances, such as pesticides. The idea has wide applicability and requires further research into areas of use in laboratories, workshops, and other industrial workplaces. This emerging technology acts as a catalyst for the established disciplines of fashion, textiles product design and many others, to collide, interact, and innovate.

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