Parametric Design for online User Customization of 3D Printed Assistive Technology for Rheumatic Diseases

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Abstract. New spaces for the co-creation of Assistive devices have been increasing according to the current lack in specific products for everyday user needs satisfaction. Moreover, Open Innovation is gradually increasing the user role in product development thanks to new digital technologies spread. Nevertheless, the knowledge and the affordance of this bottom-up solutions is still limited amongst the potential users.
The aim of this work is to show and investigate one application of the Virtual Reality related to Assistive Technology customization, as well as the customization process for the user. Starting from a Co-design approach, variables for customization were detected on specifically co-created products for users with rheumatic diseases. By means of specific 3D modeling tools and an online platform, an Open Source online configurator was then developed for the customization of these products. In this way, customized STL files of the objects can be downloaded and created by using low cost Additive Manufacturing technologies. Consequently, affordable Assistive products for specific needs can be easily spread, increasing the users quality of life.

Keywords: Parametric Design, Customization, Assistive Design.

1 Introduction

Assistive products focused on rehabilitation and medical treatments can be generally provided by following the guidelines and indications provided by the hospital institution or the professional figures involved in a specific therapy. Therefore, their purchase is quite easy. Because of the stigma related to their use for their pronounced medical aesthetics and a partial user need satisfaction, abandonment rates for this kind of product is considerably high [1].

In addition, another assistive products category could be individuated. More in detail, this kind of tools are employed mostly during users everyday activities, and they specifically fulfill patient's needs, according to their disease. Even though they are less known from the users than the previous ones, their use is a valuable solution for improving the quality of life [2].

The final authenticated version is available online at
https://doi.org/10.1007/978-3-030-58468-9_14

Thanks to the spreading of Open Innovation and Co-creation phenomena [3], some projects related to assistive tools co-design have been developed. Consequently, the user is assuming an even more centered role in defining his own needs, and digital technologies (e.g. low cost Additive Manufacturing) are the most suitable media for this aim [4, 5]. Nevertheless, the resulting assistive products are not enough affordable for the users at the moment. Their knowledge amongst the potential users is not well-established, consequently the purchase of this kind of assistive products is complex. Moreover, only certain tools can be customized considering the specific user needs, resulting in less suitable solutions. For these reasons, the use of Virtual Reality (VR) environments and the Open Source approach can be a promising way [2, 6].

In this paper, a VR environment application for customizing assistive design products for users affected by rheumatic diseases is introduced and explained. Specifically, the present work is part of "Noi Non Ci Fermiamo" (NNCF) project related to assistive products co-design considering rheumatic diseases impact on specific daily needs. Starting from the workflow and the tools used during the project, an online configurator for user was developed by using a parametric design definition uploaded on a specific customization platform. In this way, Open Source customizable assistive products can be purchased directly from the user. Main results about this VR application and the resulting customization processes are then described, including the main implications. At the moment, this work can be considered one of the first methods for involving the user, and increase the effectiveness and affordability of the assistive products, reducing also their abandonment rates.

2 Methods

2.1 Workflow

This work has been performed in the 3D Printing and Materials Laboratory +LAB of the Department of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano, Italy.

Nine users affected by rheumatic diseases and two occupational therapists participated to the project together with the design team during the brief definition, concept generation and product development phases. The steps were useful for defining the assistive products to be designed during the project, starting from unsatisfied real user needs in everyday activities. These products were obtained by using a strongly Co-design oriented approach that actively involved the selected users through the whole design process as co-designers [7]. As a consequence, the same products were used as a starting point for the current experimentation.

During the product development, variables (or parameters) that should be considered for the customization of each product were identified with the co-designers' feedback. In this way, the customization work was limited only to parameters and pieces with a tangible benefit from the customization itself, avoiding issues related to a large variety of customization parameters for the users [8].

Then, the parametric definitions for the customizable pieces were obtained by considering the chosen parameters. For each of them, the lower and the upper limit of the value variation was set considering the overall product shape, the physical prototypes tested from the co-designers, their feedback and the specific product usage scenario. Moreover, anthropometric studies [9] were also taken into account for a better value definition.

Further modifications to the definitions were performed for integrating and improving the user experience related to the online customization through the configurator (i.e. selection of the piece to visualize). Finally, clear instructions for the final user were generate by testing the products assembly, and the configurators have been spread online for the users.

2.2 Tools

During the project, different software have been used according to the different design needs. Firstly, 3D modeling software were adopted through the design phase of the assistive products: concepts and non-customizable pieces were made with Solidworks (Dassault Sistèmes, France) and Creo Parametric (Parametric Technology Corporation, US) CAD systems. For customizable pieces, Rhinoceros (Robert McNeel and Associates, US) and Grasshopper (GH) plugin for Rhinoceros (Robert McNeel and Associates, US) were the main tools adopted.

Shapediver online platform for Grasshopper definitions and Shapediver Materials Add-On (Shapediver, Austria) were adopted for managing the Online User Customization of the assistive products. The resulting 3D interfaces were then inserted in "+Ability" website together with the non-customizable parts models and assembly instructions in order to be accessible from the users for the physical realization.

Gcode files for 3D printed trials were created by using Cura (Ultimaker B. V., Holland) or Slic3r PE 1.41.3 open source slicing software (Prusa Research, Czech Republic). Subsequently, Delta 2040 (Wasp S.r.l., Italy) or Prusa i3 MK3S FDM 3D printers (Prusa Research, Czech Republic) were used for the 3D printed parts. According to the specific technical requirements, they were primarily made with PLA, PETG or TPU (90 Shore A) filaments or, alternatively, by casting silicone with mid Shore A values in 3D printed PLA molds.

3 Results and Discussion

3.1 Online User Customization Configurator

Parameters Selection. Similarly to the product development in NNCF project, the user customization configurator development started with a Co-design phase during the first usability tests. In this case, its purpose was firstly to identify the parts of each product that should be customized from the final user. Then, the most important parameters for the customization were detected for the resulting parts.

Secondly, parameters range variation had to be defined considering not only the specific co-designer need, but also taking in consideration the whole usage scenario. For this reason, tests with different 3D printed prototypes have been performed, as well as anthropometric guides have been considered. An overview on the selected customizable pieces and customization parameters for each product is visible in **Table 1**.

Table 1. Variables for the User Customization for each Product of NNCF Project

Product	Customizable Parts	Parameters for User
Le Micheline (Handles for Cutlery)	External Grip Internal Core	Product height, width Handle Outline Cutlery to handle
Angie's Brush (Hair Washing Brush)	Handle Mold Internal Core	Handle height, width, outline Surface grip presence
Daisy (Bottle Opener)	External Holder Inserts for plastic bottle caps	Insert types, Product height Holder width and outline
Pinzamisù (Credit Cards Pliers)	Main Body	Product dimensions Handle width Grabbing angle variation
Pinzamigiù (Credit Cards Pliers)	External Grip Internal Core	Product dimensions Handle width
L'Hook (Safety Belt Grabbing Tool)	Handle Handle Fixing components	Handle width Internal core diameter
Scarpe Diem (Telescopic Shoehorn)	Handle	Handle height, width, outline
Manola (Objects Pick-up Tool)	Handle	Handle width, outline

Product Customization settings. Consequently, 3D models were generated by creating the GH definition starting from the above-mentioned parameters. Each of them was set by using the proper components combination. Number Slider and Value List components were the most used ones in case of numerical variation, such as dimensions.

For more complex variations (i.e. outline or shape-related features), a combination of Value List, Evaluate and Cull Pattern components was adopted. More in detail, the different outlines were previously created through a specific definition into the GH canvas. For each of them, a consequential integer number has been defined in the Value List component. Contemporarily, the outlines have been linked to the Cull Pattern component, which in turn is linked to the Evaluate one. By defining a repeating true/false pattern with If-then conditional expressions, it is possible to choose only a specific outline by changing the Value List selection. Therefore, outline customization would be possible by choosing from a list of different preset shapes made in accordance with the starting co-designers' feedback.

The If-then conditional inserted in the GH definition was set as it follows:

```
If(x=N, true, false)
```

where x is the variable, and N is the consequential integer number of one a specific outlines in the Value List. A GH definition example for shape customization from three different outline alternatives is shown in **Fig. 1**.

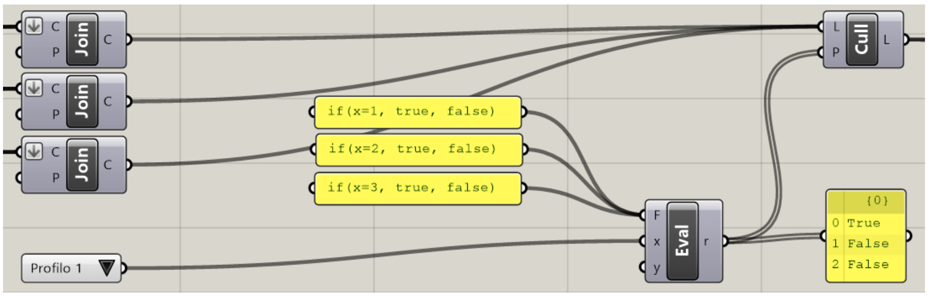

Fig. 1. GH definition example for shape customization through Value List (Profilo 1 component) from three different outline alternatives (Join components)

Configurator settings. After the parametric 3D model definition, configurator settings should be defined for an easy customization process for the user. In this case, settings were defined both in the GH definition and in the ShapeDiver online platform website [10]. This is due to the fact that interface issues were mainly related to the online platform settings, while the parts visualization and download managing had to be previously defined in the GH definition.

For this reason, the parametric 3D model was affected not only by the product definition and its customization possibility, but also by the interaction between the user and the configurator itself. Consequently, the If-then conditional approach was also adopted for the visualization of two or more parts of from an assembly (**Table 1**). In fact, the user should clearly understand which part is going to be modified during the customization for a better experience. Thanks to the If-then conditional, he could define on his own the parts to be shown during the configuration process. Further modifications were made for including STL download settings, and they were set in the definition thanks to the Shapediver Material Add-On specifically provided from Shapediver.

As an example, the GH definition of Daisy bottle opener for the online user customization through the configurator is visible in **Fig. 2**. The 3D model construction for each customizable piece is linked with the User Customization variables. Then, the outputs are linked with the STL File exporting settings for the download and with the configurator visualization settings.

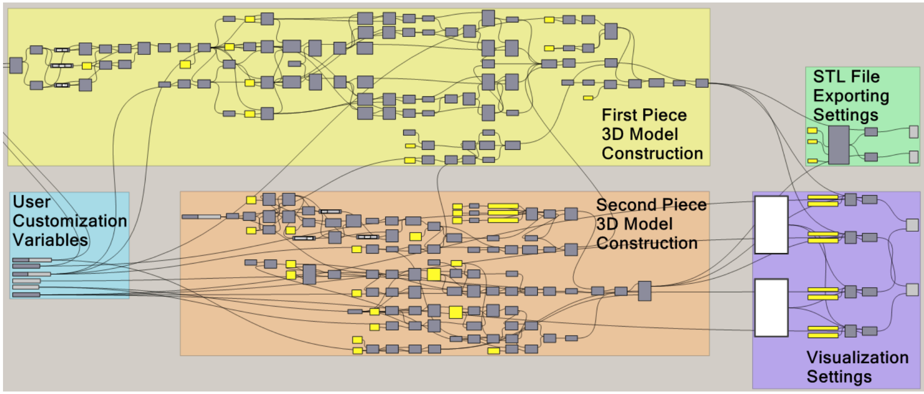

Fig. 2. GH definition organization of Daisy bottle opener 3D model for the online user customization

Finally, the interface settings of the online configurator were performed on the platform website. It has been possible to set the visualization of the user variables, as well as the 3D model visualization in the virtual environment. Its interface is visible in **Fig. 3**.

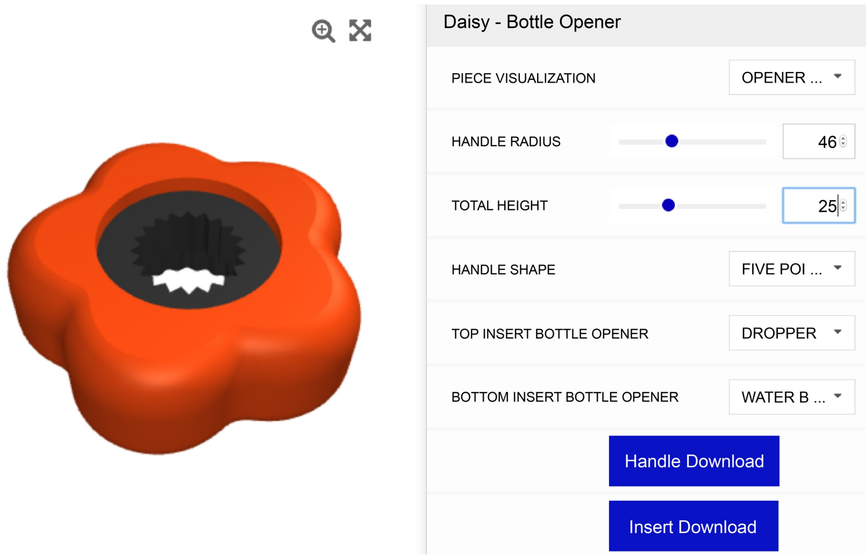

Fig. 3. Online User Configurator interface for Daisy Bottle Opener Product

Discussion. Considering the configurator developing, added-value has been generated from the starting Co-design phase focused on parameters individuation. However, the designer should sort the co-designers' output in order to avoid Mass Confusion issues related to a high number of detected variables.

In addition, the selected parameters for the GH definition development were primarily related to the geometry of the 3D model itself. Other kinds of variables for customization such as colors, materials or finishing were considered differently, since their managing was not completely controllable during the creation of the GH definition. In fact, colors selection could be possible by adding a Value List component in the GH canvas, but it would not generate a real constraint on the GH definition. Moreover, the STL file cannot be affected by the color choice. As a consequence, this parameter was set as a free choice for the user, that would decide it after the STL file generation. Since standard performances of the final product should always be guaranteed, materials and finishing variables were not free for the user, but they were strictly defined from the instructions provided on the +Ability website.

Even though If-then conditionals allowed to better define the configuration process, they were adopted maximum twice in a single GH definition. This is mainly due to the amount of milliseconds that each real-time modify on the parameters requires for being updated, depending on the components in the GH definition. Consequently, an excessive utilization of the IF-then conditional combination could generate remarkable delays in real-time modification during the configurator use, affecting negatively its performances and also the whole user experience.

3.2 Online User Customization

The online user configurators and the related customizable assistive products were subsequently inserted in the +Ability website [11] together with the non-customizable parts (STL files) and the assembly instructions.

Some variants of Daisy Bottle Opener product can be seen in **Fig. 4**. They were obtained by using the online user configuration and 3D printing the resulting STL files according to the related instructions.

Fig. 4. Daisy Bottle Opener Product Variants obtained by the STL files customized with the online user configurator

In this way, NNCF project is accessible for the users, and the 3D models could be freely purchased. Through a Creative Common Open Source license, the files can be customized and downloaded for being 3D printed and assembled, and the only costs for the users will be linked to the parts production and buy components purchase.

The online user customization process can be summarized in **Fig. 5**. Firstly, the user has to identify his need and, consequently, the most suitable NNCF product available for the customization from +Ability website. Accordingly, he should take some simple measurements for the customization (i.e. palm of the hand), or refer to everyday object measures (i.e. jars or bottles). So, the user can customize his own product from the online configurator, and the 3D model will be updated in real-time thanks to the VR environment. When the user is satisfied, the customized STL files of the 3D model can be downloaded by clicking the proper button into the environment. From the website, the user should also download the non-customizable STL files of the selected product and the corresponding assembly instructions.

By this point, STL files can be used for 3D printing the product independently or by means of a 3D printing service. Finally, the final product can be easily assembled directly by the user according to the instructions.

Fig. 5. Customization workflow of the user configurator system (from user need to its satisfaction): references measuring, user online customization of the product, download of the STL files and instructions, STL 3D printing, assembly with the required buy parts from the instructions

Discussion. Through the development of the online configurator explained before, specific user needs can be promptly satisfied. In fact, users can purchase a customized product in an easier way than using traditional channels. Moreover, the purchase can be done “on demand”, which means only when the product is needed. So, this VR application can give a solution to the lack of customized and easily accessible assistive products.

The Open Source distribution of the customizable products through the online user configurator brings the advantages and disadvantages of the Open Innovation and Co-creation practices. Consequently, its use is encouraged and spread by the Creative Commons License, even if some expedients should be considered for safeguarding the authorship of the design products and configurator work.

4 Conclusions and Perspectives

To sum up, an online VR configurator starting from user needs has been developed for spreading Open Source customizable assistive products to be produced via low cost additive manufacturing technologies. Moreover, its developing process and the user customization procedure have been furtherly explained and discussed.

Finally, some other aspects need a deeper investigation. This VR based configurator could be adopted also for customizing other assistive products focused on different kind of diseases, and further work could be done for various everyday needs. Other kinds of variables for customization could also be implemented, especially considering the tactile an senso-aesthetic properties of the products. In addition, an exhaustive analysis from an economical point of view could be performed. To close, VR allowed the affordability of specific customized assistive products from the users, creating a virtuous connection between people and technology for an increased quality of life.

Acknowledgments. This work is part of NNCF (Noi Non Ci Fermiamo) project developed at +LAB 3D printing Lab (Politecnico di Milano) in collaboration with Roche S.p.A. The authors would like to thank the Italian rheumatic diseases patients associations ANMAR, APMARR and ALOMAR, the users, the occupational therapists and the design team involved in the project. They also gratefully acknowledge the support of Shapediver online service during the User Configurator development.

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