MASARYK UNIVERSITY

FACULTY OF INFORMATICS

Configurator for 3D Printed Generative Jewelry

Master's Thesis

HANA TOKÁROVÁ

Brno, Spring 2024

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FI

Declaration

Hereby I declare that this thesis is my original authorial work, which I have worked out on my own. All sources, references, and literature used or excerpted during elaboration of this work are properly cited and listed in complete reference to the due source.

During the preparation of this thesis, I used the following AI tools:

- **Grammarly** for grammar check and spelling,
- **Github Copilot** for code documentation and faster code writing,
- **ChatGPT** for bug fixing.

I declare that I used these tools in accordance with the principles of academic integrity. I checked the content and took full responsibility for it.

Hana Tokárová

Advisor: Mgr.art. Helena Lukášová, ArtD.

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Abstract

Nowadays, the usage of 3D printing technologies has grown immensely in various industries, including the fashion industry. Fashion designers are trying to appeal to customers with customizable products via product configurators that help to express one's uniqueness. Additionally, the creation of customizable products can be beneficial with the usage of 3D printing methods. This thesis focuses on designing and implementing the Neotaku website, a configurator for 3D printed generative jewelry, where users can choose from four different jewelry types within two jewelry collections. Users can change various parameters for the given jewelry type, visualize the 3D model in various materials, and save the given 3D model of the jewelry. To test the tool's user interface, a qualitative user study was conducted, which showed that users enjoy the usage of jewelry product configurators and would like other features on the website, like a mockup viewer. Additionally, a jewelry expert evaluated the website, as well as four different types of 3D printed jewelry with three different 3D printing techniques. The expert evaluation demonstrated that the website offers a pleasant experience when creating one's jewelry, and the 3D prints showed examples where different 3D printers have their benefits and limitations.

Keywords

product configurator, jewelry, 3D printing, generative design

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Introduction

3D printing as an Additive Manufacturing (AM) method has become an essential element of the manufacturing process since the 1980s. It can be used in various fields to help cut production costs or innovate products using the newest fabricating trends. This trend of 3D printing has arrived in the fashion industry, where designers are creating more customizable fashion products for customers.

Nowadays, one of the most popular customizable products among customers is jewelry, which holds a status as a product that can express one's individuality. Because of this, product configurators are getting much attention besides 3D printing in the fashion industry. However, creating a configurator for 3D printed jewelry must meet certain conditions for 3D printing to work and for the customer to be satisfied with the product.

To see if the jewelry configurator can be used as a tool of self-expression via customizable 3D printed generative jewelry, various 3D printing techniques and configurator solutions must be analyzed. The theoretical part of this thesis analyses various 3D printing methods, their benefits and drawbacks, and their usage in the fashion industry. Additionally, this thesis analyses the world of product configurators, with their advantages/disadvantages and existing solutions for fashion configurators.

The discoveries made in the theoretical part of the thesis are then used in the practical part for designing and implementing a jewelry configurator website called Neotaku, which consists of a configurator for two collections of generative jewelry with four different jewelry types.

Following the implementation of the configurator tool, a qualitative user study was conducted on the Neotaku configurator to test the website's user interface. The study's final remarks showed that users enjoyed customizing jewelry on the website; however, users would like more features to visualize a given jewelry model. Furthermore, an expert evaluated the Neotaku website and its 3D prints, seeing that the website offers a pleasant experience and that the final 3D prints can be enjoyed and created by 3D printing enthusiasts or a general audience.

1 World of Configurators and 3D Printed Jewelry

Both product configurators and 3D printing methods have gained much attention thanks to their customization properties. Nowadays, these techniques can be intertwined, creating an opportunity for new, unique products for a general audience. Furthermore, these methods can be used for jewelry creation.

This chapter introduces the concept of 3D printing and product configurators in general and in the fashion industry. At first, Section 1.1 mentions the view of how traditional jewelry is portrayed in society, and Section 1.2 defines 3D printing methods used in various industries. Then, Section 1.3 defines product configurators and describes their history and variations. Specific examples of fashion and jewelry product configurators can be found in Section 1.4. Additionally, all significant benefits and challenges of configurators can be found in Section 1.5.

1.1 Jewelry

Throughout humankind's history, jewelry has been an expression of various concepts and thoughts; people communicate through jewelry different information such as individuality, aesthetics, status, money, or other cultural references [1]. Nowadays, jewelry still has its meaning to individuals and society. Additionally, as the jewelry industry is closely tied to the fashion industry, they share similar trends with one another [2]. With the clothing and jewelry industry combined, the purpose of the jewelry can be amplified via clothes.

There are different types of jewelry to choose from. Each jewelry piece is meaningful via various cultural connotations, from earrings and pendants to rings and necklaces. Furthermore, each mentioned jewelry type can have several variations. Regarding materials, traditional jewelry consists of metals like silver, gold, or brass, which can have attached gemstones such as diamonds, emeralds, opals, or pearls. This traditional jewelry is often handcrafted to give individuals high-value jewelry. However, more intriguing methods and materials became popular in the 1980s in the jewelry industry with the rise of 3D printing [3].

1.2 3D Printing, its Versatility and Limitations

3D printing methods can be seen in various fields, such as fashion for producing 3D printed clothes, architecture for 3D printing prototypes of architectural models, and even in medical fields for creating 3D printed medical devices. Even though the purpose of 3D printing differs, it can bring various benefits and limitations to each field.

1.2.1 3D Printing Definition and Methods

As defined in [4], 3D printing is an Additive Manufacturing (AM) method, which joins material specified by 3D model data in a specific format. This process of material build-up from a 3D model file is used nowadays in every 3D printer and has been used since the 1980s when the first so-called Stereolithography (SLA) 3D printer was created by Charles Hull [5]. The market for 3D printers has grown tremendously since then, and 3D printing technologies have evermore expanded. Nowadays, 3D printing methods can be differentiated into three categories: Fused Deposition Modeling, Stereolithography, and Selective Laser Sintering.

Fused Deposition Modeling

The Fused Deposition Modeling (FDM) method is one of the most popular methods of 3D printing. One of the reasons for its popularity is that FDM 3D Printers are commonly used as entry-level printers thanks to their easy manipulation and service. In principle, FDM builds models in thin layers of melted filament distributed through a deposition nozzle [6]. Furthermore, the deposition nozzle moves within a specific x- or y-axis layer. After finishing a layer, the nozzle moves up on the z-axis by predefined layer thickness to start a new layer, and the thinner the layer is, the more detail is defined in the final print. However, building supports for overhung areas for more complex forms is necessary.

FDM printers can be commonly used with thermoplastic filaments that can withstand higher temperatures, such as PC, ABS, or PLA, that are ready for the 3D printing process in spools for straightforward feeding of the material into the 3D printer [7]. After the 3D printing process, 3D printed models can undergo some visual changes in the post-process, which consists of support removal, sanding, or other methods that depend on the desired effect.

All in all, FDM 3D printers are not that cost-heavy, thanks to their low maintenance, material, and post-processing costs [8]. They are commonly used for prototyping 3D printed models, and their overall quality of final 3D printed models can not compete with other 3D printing methods such as SLS and SLA.

Stereolithography

Stereolithography (SLA), used in the first AM 3D printers, is a method of curing photosensitive resin via laser beam, which creates the final 3D printed product [9]. The preparation of SLA printing varies differently from FDM and can be much harder to maintain and clean. In order to prepare the SLA 3D printer, the reservoir must be attached to the machine so it does not move, and after that, the build plate, which will have the final 3D printed model, is mounted [10]. Then, the laser beam cures resin based on the given 3D file of the model layer by layer, and the plate moves according to the layers to continue with the 3D printing. Additionally, as with the FDM method, SLA creates supporting structures for the 3D prints to stay in place.

As the SLA 3D printers use liquid resin as a building material of the 3D model, the final 3D printed models are watertight and can obtain higher resolution details than FDM 3D printers [11]. However, there are more steps in the post process; firstly, the surplus resin that is covering the model needs to be washed through an alcohol or ether wash, and then, the 3D printed model needs to be cured with a UV lamp for a specific time depending on the resin type.

To summarize, as the first AM printing method, SLA is more expensive for the maintenance and services of 3D printers. However, unlike FDM printing methods, it can create higher-resolution models through various resins that can be used for models with finer details.

Selective Laser Sintering

Selective Laser Sintering (SLS) is another standard method for 3D printing. Unlike FDM or SLA, in this method, a laser beam melts a powder, binding the powder together and creating a 3D printed product [12]. During the process, the powder is spread out via roller as another layer onto the platform where the final 3D model is being built [13]. The platform moves during each layer to start another layer. Unlike the FDM and SLA, SLS does not require structure supports, as the whole 3D model lies in the unused powder, which supports it, and that can be reused again for a new model.

SLS printing can use various conductive polymers, nylon, carbon fiber, and various other types of natural polymer [14]. Additionally, the SLS post process is easier than SLA without material curing because of the features of the printing method. However, the final 3D printed model must be cooled down and cleaned from excess powder, and additionally, the 3D printed model can be smoothed out for better texture.

Overall, the SLS printing method creates 3D printed models that do not show thin layers, and unlike FDM or SLA, it can be used for functional prototypes or high-defined 3D models. However, the cost of SLS printers is substantially higher than the SLA or FDM printers, which makes them unusable for smaller projects or independent users.

1.2.2 3D Printers Benefits and Limitations

Each one of the methods mentioned above has its pros and cons. However, it is wise to choose the method and material according to the given requirements regarding durability, quality of detail, size, and others.

3D printers as an AM method are becoming advanced and a preferred solution for manufacturing methods in professional business settings. As seen in [15], 3D printing technology has many advantages over traditional manufacturing, such as industrial efficiency, mass customization, or on-demand manufacturing. Furthermore, the 3D printed models can serve as low-cost mockups for easier prototyping, and thanks to the various techniques of 3D printing, the time in which the mockups can be produced is rather quick [16].

Unfortunately, 3D printing has several drawbacks. As seen in [17], these problems vary from material-related challenges to architecture and design challenges, such as printability, buildability, or structural integrity. Additionally, even though 3D printers are faster than traditional manufacturing methods, some 3D printed models still take days to finish, and the issues of maintaining 3D printers and post-processing models need to be addressed as well [18].

1.2.3 3D Printing in Fashion

As 3D printing technologies have found their place in various industries, the fashion industry has also started to use this manufacturing method for new projects and perspectives regarding the fashion world.

The shoe industry is one of the first to experiment with 3D printing. As seen in [19], various designers are already experimenting with 3D-printed shoes with various materials and infills that could be worn. Also, there are already research studies for programs that could create soles for traditional shoes using 3D printing [20]. For the products that can be already bought, shops like Zellerfeld[1] or Koobz[2] already offer 3D printed shoes with customized shoe fit.

In addition to the shoe industry, the clothing industry is adding 3D printing technologies to its products. The primary use of 3D printing in the clothing industry is to create various geometric structures connected as a chainmail or weft knit for easy movement [23]. Another way of using the 3D printed model is as one big statement piece, which creates an exoskeleton aesthetic [24]. However, the main issue with these two usages is that they differ from the traditional daily clothes. Fortunately, new methods of 3D printed clothes are emerging, such as weaving the 3D printed material as in traditional garment making [25]. For now, there are already some designers that use 3D printing techniques and revolutionize how to think about clothing garments, such as Irvis Van Herpen[3] or Julia Daviy[4].

Lastly, the eyewear and jewelry industry also started incorporating various 3D printing techniques into their manufacturing process. For the eyewear industry, 3D printing allows the creation of new designs

1. *Zellerfeld* [online]. [visited on 2024-05-08]. Available from: `https://www.zellerfeld.com`.
2. *Koobz* [online]. [visited on 2024-05-08]. Available from: `https://koo.bz`.
3. *Iris van Herpen* [online]. [visited on 2024-05-08]. Available from: `https://www.irisvanherpen.com`.
4. *Julia Daviy - Sustainability Innovator, Inventor and Pioneer Behind Sustainable 3D-Printed Fashion & Clean Tech* [online]. [visited on 2024-05-08]. Available from: `https://juliadaviy.com`.

of eyeglass frames, which are already used in brands like Monoqool[5]. Furthermore, brands in the jewelry industry started using 3D printing, like OLA[6] or Boltenstern[7], to create various jewelry types with several materials.

1.3 Product Configurators, their History and Differences

Product configurators offer multiple ways to design and create specific applications for the target audience. Because of the configurator's variability, in-depth research is needed to fully understand what they are capable of and what other options will be available in the future.

1.3.1 Product Configurator Definition

The definition of a product configurator can be obtained via its main feature, the customization process. As explained in [31], the customization process is "an exercise of configuring a product by selecting pre-designed modules and features within the pre-determined scope of offered variety." With the provided definition of the customization process above, a product configurator is a tool enabling the customization process of a specific product.

1.3.2 First Attempts

What can be considered as the first used "product configurators" are the brochures or catalogs providing a list of products. Even though the customer could not customize the product entirely, some features of the given product could be changed, such as the color of a car or the size of a specific garment. Nowadays, magazines and catalogs are still frequently used even though the digitalization process persists in multiple industries [32].

5. *Monoqool* [online]. [visited on 2024-05-08]. Available from: `https://monoqool.com`.
6. *OLA - 3d printed jewelry* [online]. [visited on 2024-05-08]. Available from: `https://www.olajewelry.com`.
7. *Unique Designer Jewelry | 3D Printing & Custom Made | Boltenstern* [online]. [visited on 2024-05-08]. Available from: `https://boltenstern.com`.

Special consultations with product experts were possible for customers who wanted more personalization in their products. However, this process could take much longer. Therefore, creating a given product could take time as it was made specifically for one customer. However, the product's price could rise, and customers could quickly pay more than for an un-customized product.

1.3.3 Rising Popularity of Configurators

When the online shopping experience became more popular, catalog-like shopping and tailor-made customization were brought over to offer these features. Additionally, this era introduced online 2D product configurators. The 2D product configurators now offer features combining catalog and tailor-made experience, like choosing a specific color or size of a wardrobe with enclosed photos of the product, as seen in Figure 1.1. However, even though 2D product configurators feature only an image that could have certain features changed based on specific models, they help bring the customization aspect to the customer quicker and easier than consultations with a product expert.

Figure 1.1: IKEA's configurator for the PAX/FORSAND wardrobe [33].

There are various reasons as to why product configurators have gained much popularity. One of the main reasons was the COVID-19 pandemic, which caused a shift towards online shopping [34]. Moreover, online shopping continued to be used even after the pandemic. This shift to the online world has made online product configurators much more prominent.

Another reason for the rise of product configurators was the web technologies that could do more than show 2D models. Libraries such as Three.js[8] or Babylon.js[9] are now able to show 3D models and configure each 3D model via code, which can then be used to create product configurators as well (see Figure B.1). Online product configurators with these libraries have already been used and experimented with. However, companies often develop online product configurators through their closed-source solutions.

1.3.4 Product Configurator Trends

Most product configurators use only simple input systems such as buttons, drag and drop, or moving of a particular object. On the other hand, new configurators are trying to add more customizability options via sliders, changing the given parameters of the 3D model. These so-called parametric product configurators are already seen in various brands, such as interior design visualization from Kilo[10]. Additionally, parametric product configurators create more generative options for the customers to build and create a unique product for each customer to their liking.

Augmented Reality (AR) has also begun to show in product configurators. With the ability to display any 3D model anywhere in real 3D space, AR shows potential for visualizing 3D mockups of products in real-time. With brands like Adidas[11], AR is becoming more prominent in the industry with the option to "try" 3D models of the Adidas shoes in real-time. Virtual Reality (VR) could also benefit other product configuration areas, such as the car industry or home planning. This "virtual store" could work for customers wanting a more immersive experience from the product's try-on. One example of a virtual store can be seen in Dyson's VR experience set[12].

8. *Three.js – JavaScript 3D Library* [online]. [visited on 2024-01-25]. Available from: `https://threejs.org/`.
9. *Babylon.js: Powerful, Beautiful, Simple, Open - Web-Based 3D At Its Best* [online]. [visited on 2024-01-25]. Available from: `https://www.babylonjs.com/`.
10. *Kilo* [online]. [visited on 2024-01-25]. Available from: `https://www.kilo.nl`.
11. *adidas Official Website* [online]. [visited on 2024-01-25]. Available from: `https://www.adidas.com`.
12. *Dyson Demo VR* [online]. [visited on 2024-01-25]. Available from: `https://www.dyson.co.uk/discover/news/latest/dyson-demo-vr`.

Thanks to the 3D models of online product configurators, customers can visualize more accurately how the product could look; however, customers can still be limited by its features. With the rise of the popularity of artificial intelligence, such as the OpenAI[13], artificial intelligence can now create texts, pictures and 3D models as well [41]. Users can create specific 3D models without any 3D modeling skills with simple text input. This new feature was not used commercially in 2023; whether it could be used later is still open.

1.4 Existing Solutions for Fashion Accessory Configurators

As Section 1.3 mentions, many configurators visualize and change products differently. For the analysis of several product configurators, seven examples of configurators are described here in detail to understand how they work. The first four configurators mentioned are from the jewelry industry, and the other two are from the shoe industry. Finally, all the mentioned configurators are analyzed overall.

Nervous System

One of the most popular brands for customizable jewelry is a brand called Nervous System—as their website states, "Nervous System is a generative design studio that works at the intersection of science, art, and technology" [42]. They offer various 3D prints, such as puzzles, jewelry, and interior decorations. The specialty of the Nervous System is 3D printed jewelry—their website offers fully customizable jewelry pieces with several properties to customize. The customer can choose between multiple jewelry types or collection types, as seen in Figure B.2.

Product configurators of the Nervous System change interface based on the collection as well as the type of the jewelry. For example, when customers choose a ring from the Cell collection, they can customize its shape, dimensions, size, and material via multiple options, such as sliders, number inputs, or clickable options (see Figure 1.2).

13. *OpenAI* [online]. [visited on 2024-01-25]. Available from: `https://openai.com`.

The customer can also give a name to their creation and save it, but this option is only available if the customer has an account on the website.

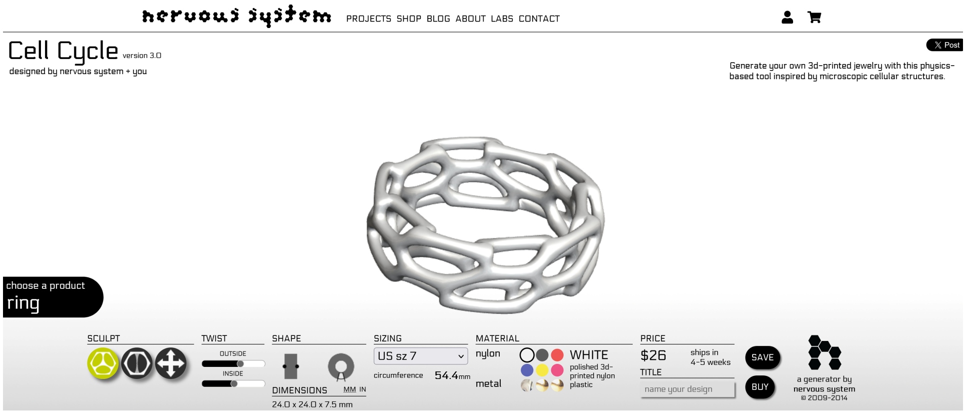

Figure 1.2: Cell Cycle ring configurator by Nervous System [42].

Digimorphé

Digimorphé [43] is another specialized brand that creates 3D-printed jewelry. This brand aims to create aesthetically pleasing jewelry with the help of parametric and generative design strategies. Furthermore, Digimorphé is experimenting with various generative methods to create designs for custom jewelry and other suitable 3D-printed products. The final touches of Digimorphé products are made using traditional handcraft methods.

Unlike other services, this product configurator aims to help the jewelry designer develop new, exciting designs for the customers. The designer will create a digital model to play with using sliders to create new designs in programs like Processing[14] or Grasshopper[15] to customize products for their customers, as seen in Figure 1.3. These designs are created at the customer's request or by the designer.

14. *Processing* [online]. [visited on 2023-11-13]. Available from: `https://processing.org/`.
15. *Grasshopper 3D* [online]. [visited on 2023-11-13]. Available from: `https://www.grasshopper3d.com/`.

Customers interested in some of the designs already created by Digimorphé can purchase jewelry in various colors and sizes on their website or contact the brand for a unique piece.

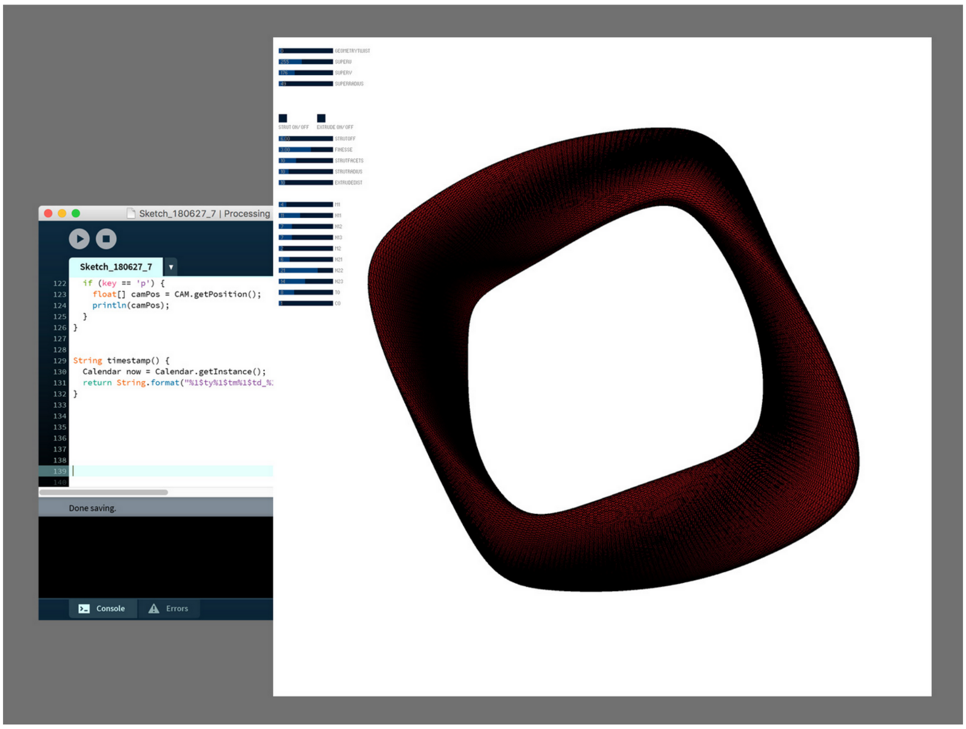

Figure 1.3: Bangle configurator in Processing [44] by Digimorphé [43].

NonExamples

Another product configurator worth mentioning is from a brand called NonExamples [46]. This brand aims to create intriguing jewelry while maintaining its quality through 3D-printed metals. One of the brand's goals is to be sustainable, which is realized by using recycled materials in newer products to reduce waste and excess.

NonExamples offers product configurators for various types of jewelry. However, they all offer customization through a menu, where the customer clicks on the demanded attributes (see Figure 1.4). To enhance the customer's experience, customers can look at the jewelry on a 3D model visualization. Additionally, NonExamples also offers accessories to order without customization process.

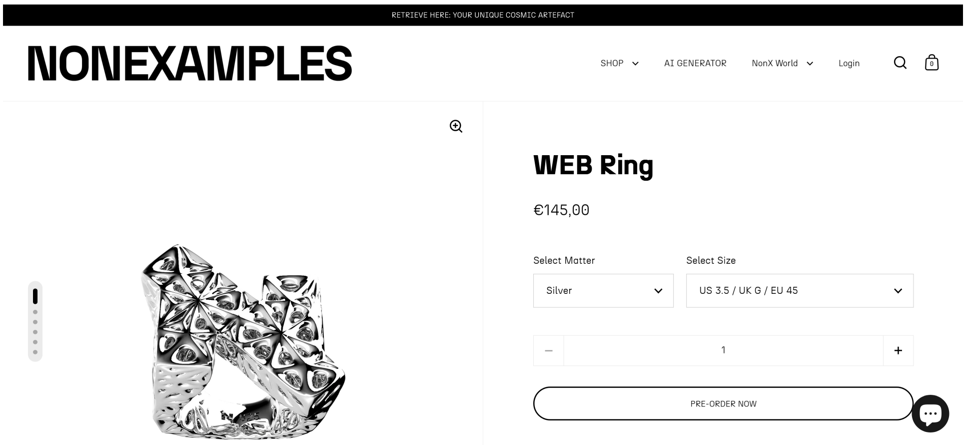

Figure 1.4: NonExamples WEB ring configurator [46].

Jweel

The last example of how to work with a jewelry configurator is from a discontinued[16] project called Jweel [47]. Jweel aimed at personalized jewelry for everyone with easy mesh customization, and it showed potential for working with customizable jewelry in other ways, as the already mentioned configurators. After discontinuing the project, the company left the configurator for others to enjoy and experiment with, with the option to export customized jewelry into .OBJ files as well.

Users can choose between three styles of rings and one style of pendant. Depending on the style of the ring or pendant, the user has different attributes that can change. For example, Jweel offers a 'text ring,' which users can use to put any text onto the ring's design. Additionally, the user can work with guides to customize the product in other jewelry types, such as the freestyle ring or the pendant. Users with an account can also save the pieces if they are unsure of their design for later changes.

16. Jweel discontinued their services because of the shutdown of the parenting company.

Nike By You

Much like jewelry configurators, shoe configurators are also getting more recognition, and one of the most popular is Nike By You [48]. Nike created this configurator for its customers who are not satisfied with the classic look of their shoes and want something more personal.

Nike By You offers the option to choose from several unique shoe models to customize. There are already some models of different types of shoes on the page with different colors to show the diversity that customers can create. After selecting the preferred shoe type, the customer can change the colors and material throughout the shoe (see Figure 1.5). Furthermore, this configurator offers an option to add text to the shoes for further customization. After the customization process, the customer can save the shoe preview, order them to buy, or share the customized pair with friends via a link. Unfortunately, the customer cannot change the shoe model or mesh in the configurator.

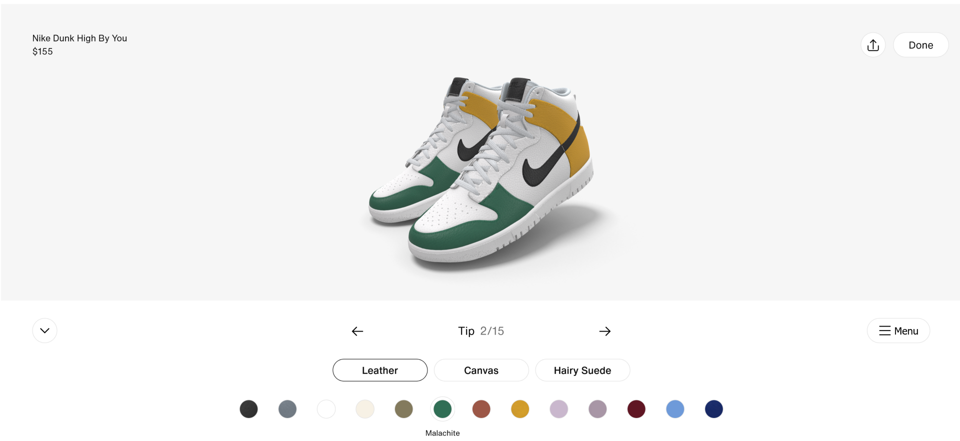

Figure 1.5: Nike By You configurator of the Nike Dunk High shoes [48].

New Balance

For other shoe configurators, Tapmod Studio created a configurator demo for New Balance shoes [49]. This configurator specializes in customizing the type NB1 997 Sport shoes. The customer can preview the shoe from different angles and change the material of some parts of the shoe based on the New Balance's colors. Unlike Nike By You, customers also have the option to click on the button to 'fit' shoes, which shows a mockup picture of how the shoes could look on a person. Furthermore, at the bottom of the demo is a list of four random combinations of different colors and materials of the shoe that can help the customer find inspiration on how to create their design, as seen in Figure B.3.

Analyzing existing solutions

All of the product configurators mentioned above work in different ways. Some use classic methods, like menus with different changing attributes; others try to be more experimental and help the customer with the shopping experience via AR functions or mockups of their customized designs. Some configurators also give customers the full option of customizability to offer creative freedom.

The field of jewelry product configurators is still in the developing stage. Therefore, some resurfacing issues can cause problems, such as how to customize the product configurators so it does not bore or overwhelm the customer with the number of options. There is also a question about the level of customizability, such as how many parameters the given configurator should have. Additionally, many existing brands offer products that cannot be configured because they do not want to or because of the used software. On the other hand, brands that use more customizable product configurators need special software to create these experiences.

Another issue when creating a configurator is the investment needed to develop the tool. Overall, brands must calculate if the configurator as a customization tool would be profitable for them. Additionally, many of the already mentioned brands with product configurators sell products that cannot be customized, most of the time for lower prices to appeal to an audience that does not need customization options. For example, if shoe companies made configurators that could specify parameters for each foot, the cost would be much higher, and some customers would not even need or want this level of customizability. Furthermore, if a brand has a product configurator, it is limited by its existing predecessor products.

What also matters is the type of models that customers can interact with. From all of the existing solutions, the products that concern the jewelry market are not as customizable as Computer-Aided Design (CAD) models. These axis-oriented CAD models are more manageable than models with organic forms. Therefore, creating a configurator for jewelry that has an organic form can take longer than creating CAD models.

1.5 Benefits and Challenges of Product Configurators

The investigation of existing solutions for fashion accessory configurators mentioned in Section 1.4 showed multiple issues arising from product configurator usage. These issues as well as benefits of product configurators are summarized below.

Customization

The first and foremost benefit of using product configurators is the customization aspect for the customer. Even though these configurators can look different from one another, they all bring more custom ways to work with specific products. This customization process means the customer is more satisfied with the product because it was made specifically for them and designed by them, improving customer loyalty overall [50].

Nowadays, the more the customer can change the product, the more positive feedback the brand will get from the customer. As seen in [51], the brand Volkswagen (from selected car brands in the study) has the most options for customizing and showing products in their product configurator, which can help the customer not only customize the necessary attributes in order to buy a car but other aspects that can be helpful to the customer as well. However, the number of parameters should be limited so customers are not overloaded with information.

Customer Connection

The connection and trust between the company and its customers are among the most critical aspects of keeping the business flowing. Trust and customer loyalty are created from the first moment the customer learns about the company, and the customer's trust about the company can grow over time.

Unfortunately, the relationship between customer and company can quickly deteriorate if the customer is disappointed with the company's products. As mentioned before, the customization level is the primary reason customers are pleased with product configurators and, therefore, want to stay in touch with a particular firm or company.

Sustainability

Another advantage of product configurators is their sustainability. One of the biggest problems when dealing with fashion products nowadays is overproduction, where fashion consumers buy more clothes than ever, contributing to environmental problems and international textile waste [52].

In some cases, the problem of overproduction could be managed with the help of a configurator. They can enhance the experience of making custom fashion pieces to give the customer more freedom to style a piece and, because of it, use the garment much more often rather than dispose of it. Moreover, these clothing pieces are not manufactured globally, creating less environmental pollution and contributing to a more sustainable mode of operation.

Software Feasibility

Many challenges can occur when developing software for product configurators. The issue with software production can depend on the company's size, whether it is a small firm or a known company. Furthermore, the products that the company makes and sells can be complicated and have many functions, and because of that, there can be various drawbacks for product configurator developers.

As explained in [53], multiple problems can arise, such as integrating the product configurator into an existing software pipeline and creating product models for the configurator, as well as a significant amount of work depending on the number of customizable products. The necessary amount of work also depends on the functions the configurator should have and the skills the configurator developers possess. Additionally, the configurator benefits from having an intuitive and user-friendly interface to accomplish tasks quickly, which presents its own set of challenges that may need to be addressed by a UX/UI specialist.

Maintenance

Another problem that can occur when dealing with product configurators is with the maintenance of the project itself. Project maintenance is one of the essential parts of software development after the product release, as it determines the future of the product and the amount of customers that will utilize it over time. Because of the time and energy that was spent on the project and its software, developers need to be able to maintain such products. Consequently, some projects can be discontinued and then become unusable.

There can be multiple factors that cause the maintenance of the project to be difficult, such as the need for more people on the project, the complexity of the solution, or technical debt. As shown in [54], companies are having complications in maintaining their product configurators because of a lack of IT designers and communication between them and the designers of the customized products. In addition, this study shows that not all designers possess the skills to work on product configurators. These maintenance problems concern not only the product configurators but also other applications [55].

Price

Price can be another vital factor for a company, determining how much money it wants to spend on specified software and functions and how much a customer is willing to pay for a customized product. Smaller companies usually need to take risks and put more of their capital into products because of their novelty on the market, which usually leads to higher product prices. On the other hand, more prominent and well-known companies can make products at a lower cost.

Large companies or smaller firms must decide if the product configuration is necessary for their business. As seen in [56], the research shows that creating product configurators can incur significant expenses. However, once the product configurator is introduced to the public and the company's customers, it can rapidly boost up sales of the company [57]. Some companies also offer mass-produced uncustomizable products, which can suit customers who do not need the custom aspect of the product or if they cannot afford it.

Time

The last important variable in the creation of product configurators that I mention concerns time. Companies need to ensure that when they use the product configurators, they have enough software developers who know how to develop them. Having employees with specific skills is necessary because development could take much longer without them. Furthermore, when the product configurator exists, and customers can use it, getting to know it and its features takes much longer. Nevertheless, longer usage times are not necessarily bad because they may help foster customer connection.

2 Designing Neotaku Configurator

The design process of a product configurator's functionality is an integral part of its creation. This chapter describes the design process of the configurator tool, from design requirements to the final high-fidelity prototype. Firstly, Section 2.1 and Section 2.2 describe design requirements and the design concept. Then, Section 2.3 describes the design of Neotaku jewelry collections, and Section 2.5 shows the visual identity of the Neotaku configurator. Finally, Section 2.4 describes the design of the user interface.

2.1 Design Requirements

The design requirements mentioned below served as a basis for designing the tool, its features and functionality, and were used in the tool's implementation.

User-Friendly Interface

For straightforward usage of the configurator, an intuitive and user-friendly interface is a must-have. Because of the various parameters that can be adjusted, special care should be applied to the user interface, so that the customers are not confused while using it.

Clearly Stated Parameters

When a user wants to adjust various parameters on the given model in the configurator, the parameters should be clearly explained—these clear descriptions about what specific parameters do should be visible to prevent user uncertainty. Additionally, the user needs to be able to see specific metrics within the parameter to use it properly.

Selection of Jewelry and Collection Types

When browsing a tool with several jewelry types and collections, it should be easy and comfortable for users to navigate the system. Because of this, the collection and jewelry types need to be clearly stated. Additionally, when users misclick by selecting jewelry type or collection, they need to be able to correct themselves.

Model Export in 3D Printing Formats

In order to save the 3D model of the configurator, the user should be able to quickly navigate to the part of the page with the export option. Additionally, because various 3D printers can use several formats for 3D printing, the export feature of the configurator should contain multiple 3D data formats.

2.2 Concept

The main idea was to create a configurator tool that would serve as a web-based app for individuals who want to create models for unique jewelry pieces, which they could then 3D print on their own 3D printer or use a 3D print commercial service. The website was designed to include two distinctive collections with four jewelry types: ring, bracelet, earring, and pendant for a necklace. Furthermore, each piece of jewelry was created to be configured, with the option to choose from predefined pieces or start from scratch. The configurator page was designed to display both general and specific collection-related parameters and visualize the 3D preview, which can be rotated and viewed from different angles. The model can also be seen in several colors and materials for better visualization. Finally, the tool had to contain an option to save a 3D file of the design to be ready to be 3D printed.

This design concept was taken into account in the implementation stage as well. Further implementation details can be seen in Chapter 3.

2.3 Designing Jewelry Collections

For the design of the generative jewelry collections, I wanted to create two collections to choose from. The collections were created to share general parameters, such as the jewelry sizing for rings or bracelets of specific height, width, and depth. The unique parameters based on the two collections, Lissaje and Torsion, were inspired by the parametric equations of known curves and surfaces. These equations were modified to generate 3D models suitable to become jewelry.

2.3.1 Lissaje Collection

As the name suggests, the first collection was inspired by the Lissajous curves, named after the French mathematician Lissajous, who studied how these curves operate in oscillations [58]. The parametric equations for two-dimensional Lissajous curves were defined as

$$x(t) = A\sin(a\ + \delta), \quad y(t) = B\sin(bt) \tag{2.1}$$

where A and B are amplitudes, a and b are sinusoidal frequencies, δ is a phase shift, and t is time/angle measured in radians. This parametric equation system can be extended into three-dimensional curves, creating even more delicate and intricate curves. The extension can be made from the Equation 2.1 of two-dimensional Lissajous curves, which gives an additional dimension to be defined as

$$z(t) = C\sin(ct + \gamma) \tag{2.2}$$

where C is an amplitude, c is another sinusoidal frequency, γ is a phase shift and t is time/angle measured in radians. This system of parametric equations for three-dimensional curves was the foundation for the Lissaje collection and the four different jewelry types present in the final app. The concept art for the four jewelry types of the Lissaje collection can be seen in Figure 2.1.

2.3.2 Torsion Collection

The appearance of twisted torus inspired the second collection, creating aesthetic waves on the jewelry's surface. This collection used a definition of parametric surface for torus [59], with the addition of several other parameters into the equations. The equations for the twisted torus for a three-dimensional surface were defined as

$$\begin{aligned} x(u,v) &= (R + r\cos(v + ku))\cos u \\ y(u,v) &= (R + r\cos(v + ku)\sin u \\ z(u,v) &= r\sin(v + ku) \end{aligned} \tag{2.3}$$

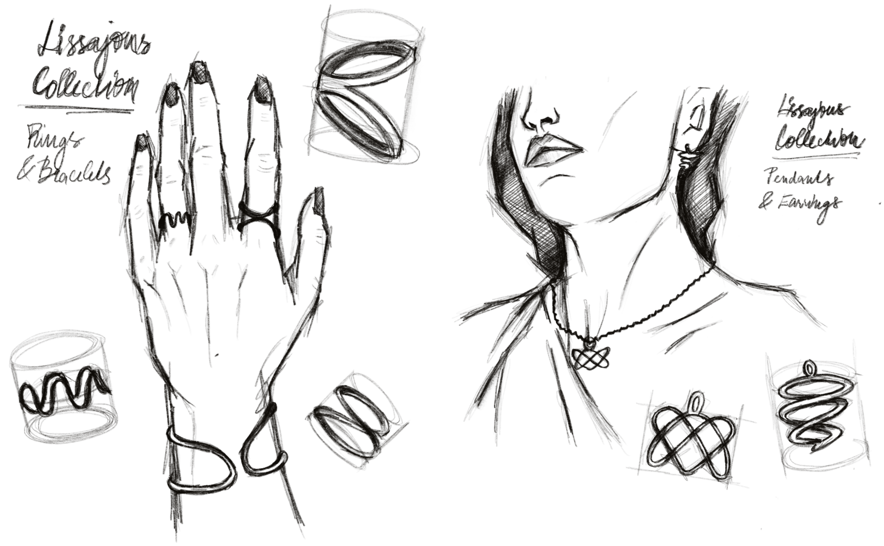

Figure 2.1: Concept art for the Lissaje collection.

where R is the major radius, r is the minor radius, k is the twisting parameter, and u and v represent the longitude and latitude angles on a sphere ranging from 0 to 2π. Additionally, the parameter k was added to the equations, which created a twisting effect around the surface of the torus. This definition of the parametric surface through Equation 2.3 for a twisted torus was a starting point for the Torsion collection. Later, in the implementation process, there were added other parameters like inflate, screw offset, tapering, or twist all as well. The concept art for the four jewelry types of the Torsion collection can be seen in Figure 2.2.

2.4 Designing User Interface

After the preparations of the tool's structure and the two jewelry collections, the process of designing a user interface began. This process was iterative, from defining the structure of given pages with

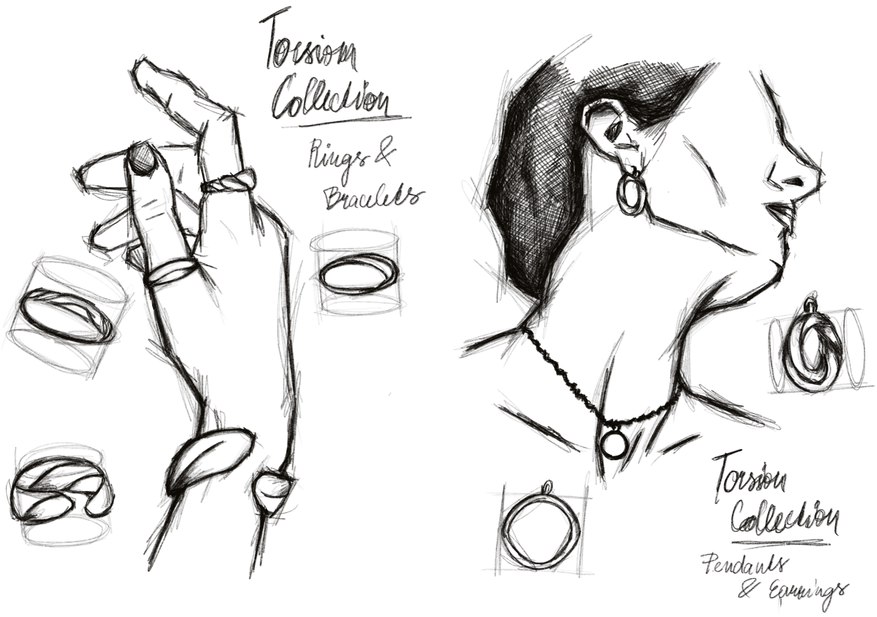

Figure 2.2: Concept art for the Torsion collection.

the features through low-fidelity and high-fidelity prototypes made in Figma[1]. The final high-fidelity prototype was then used to implement the website of the Neotaku configurator, as described in Chapter 3. The structure overview, low-fidelity, and high-fidelity prototypes are enclosed in the Appendix A in the `user-interface.zip` file.

2.4.1 Structure Overview

At the start of designing the user interface, I created a diagram of how the given tool could look like from the point of the home page (see Figure 2.3), where each node represented a specific page with its needed features. This overview helped to differentiate pages with their features and was the starting point for creating a low-fidelity prototype.

1. *Figma: The Collaborative Interface Design Tool* [online]. [visited on 2024-05-13]. Available from: `https://www.figma.com`.

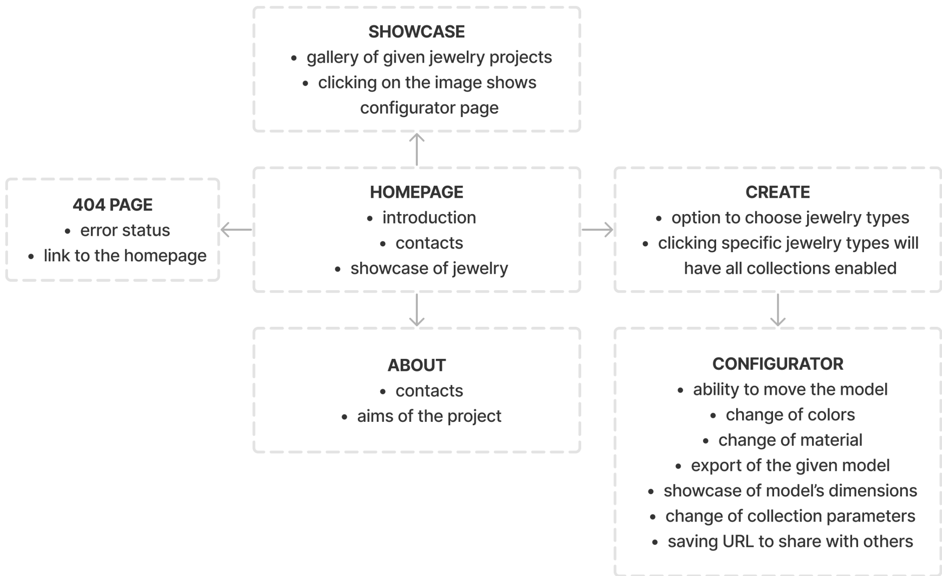

Figure 2.3: Website's structure view from the home page.

2.4.2 Low-Fidelity Prototype

Based on the structure overview of the pages as described in the previous Subsection 2.4.1, the low-fidelity (Lo-Fi) prototype could be implemented. The main point of Lo-Fi was to create a simple layout of components that could be used on different pages and that the tool would not feel "heavy" or "too much" for the user. A Lo-Fi prototype was created for desktop and mobile versions as well.

The final Lo-Fi prototype consisted of only titles, texts, and placeholder images, as seen in Figure B.4. For the layout of the different pages, the home and configurator pages were the most unique in design, as they were the most important. The layouts for other pages, such as showcase, create, or about, looked similar, so the user would not be confused with various layouts.

For the mobile version of the web page, some changes had to be made so that the content could be easily located and worked with. The most prominent change was on the configurator page, which had a mounted visualization of the 3D model at the top of the screen, and parameters were included below in a scrollable section on the page (see Figure B.5).

2.4.3 High-Fidelity Prototype

The high-fidelity (Hi-Fi) prototype of the Neotaku configurator was designed as an iteration of the Lo-Fi prototype. However, some changes had to be made to the home and create pages. The problem with the home page was that it was too similar to other pages and did not captivate the user. Secondly, minor changes were made to the creation page, specifically in the tabs for several jewelry types to be shown through a whole screen rather than a small part, and other small design changes were made on the cards of the given jewelry model. Figures 2.4 to 2.7 show Hi-Fi designs for the various pages. The high-fidelity prototype was also made for the mobile version (see Figure B.6).

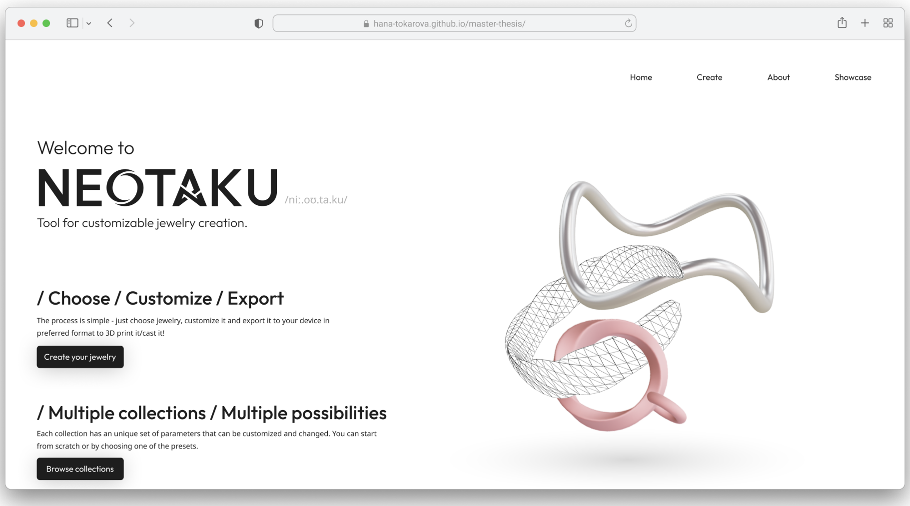

Figure 2.4: Hi-Fi design of the desktop home page.

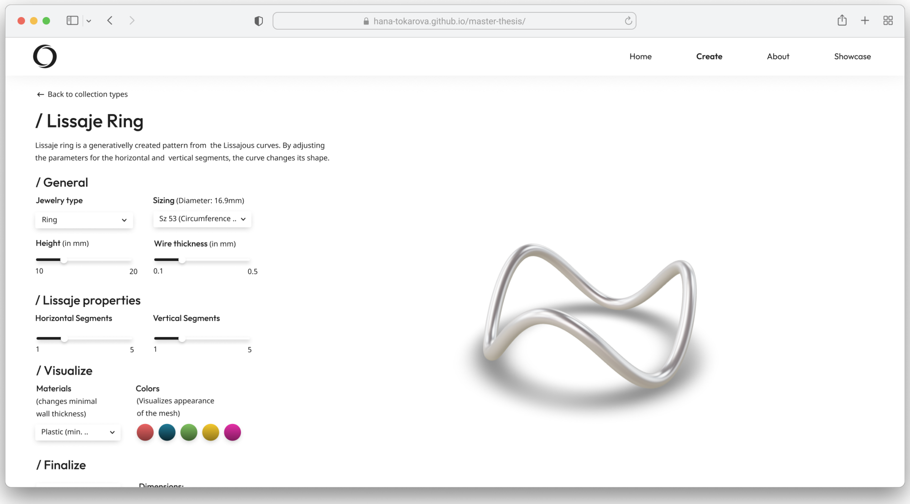

Figure 2.5: Hi-Fi design of the desktop configurator page.

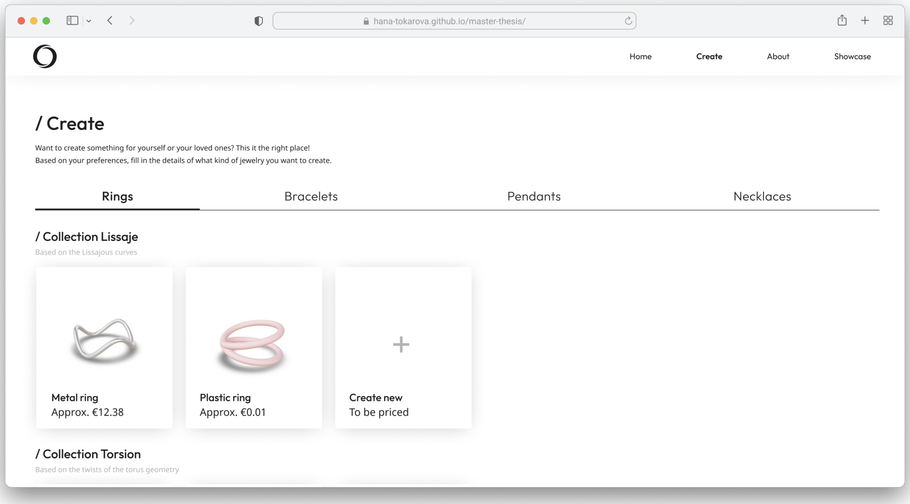

Figure 2.6: Hi-Fi design of the desktop create page.

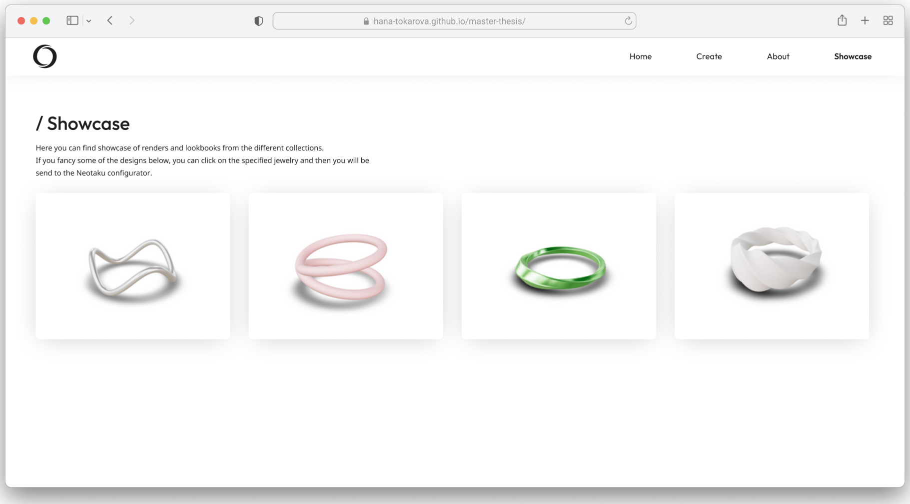

Figure 2.7: Hi-Fi design of the desktop showcase page.

2.5 Visual Identity

Visual identity is a crucial part of the design process to introduce and show the meaning of a system, brand, or tool in a creative form, which can then be recognized by a general audience. For the Neotaku configurator, it was important for the tool to be simple yet distinctive from others. The whole visual identity with the graphic manual can be found in the Appendix A, in the `graphic-manual.zip` file.

2.5.1 Logo

The logo for the Neotaku configurator was designed to be a logotype, which consisted of the name Neotaku. Neotaku, as an abstract word, represents a combination of new craftsmanship opportunities; 'neo' is new in Latin, and 'taku' is shortened from Takumi in Japanese, meaning craftsmanship.

Neotaku logotype consisted of the word Neotaku, based around the typeface Outfit[2]. The letters O and A were changed for symbols

2. *Outfit - Google Fonts* [online]. [visited on 2024-05-11]. Available from: `https://fonts.google.com/specimen/Outfit`.

representing the configurator's two collections, the Torsion and Lissaje collections, as seen in Figure 2.8. The symbol for the letter O symbolizes the Torsion collection and the twists that can be achieved in this jewelry type. On the other hand, symbol A, representing the Lissaje collection, has braiding that intersects one another, showcasing one of the many forms of Lissajous curves.

Figure 2.8: Logotype for the Neotaku configurator tool.

Icon for the Neotaku can be used instead of the whole logotype, which is the symbol for the letter O, as seen in Figure 2.9. This symbol can be used as a favicon on a website or as a button for a quick re-link to the home page.

Figure 2.9: Icon for the Neotaku configurator.

2.5.2 Colors and Typography

The Neotaku configurator's colors were minimalistic, as used and seen in jewelry brands, which incorporate colors in several materials on the given jewelry. The primary color used in the texts and buttons is off-black, contrasting pleasantly with the white background. Additional colors were also used for secondary texts and button hovers. Finally, red and green colors were added for the more straightforward navigation of users throughout the website to make a user aware of the possible warnings or pop-up dialogs for a successful task. All of the mentioned colors used in the system can be seen in Figure 2.10.

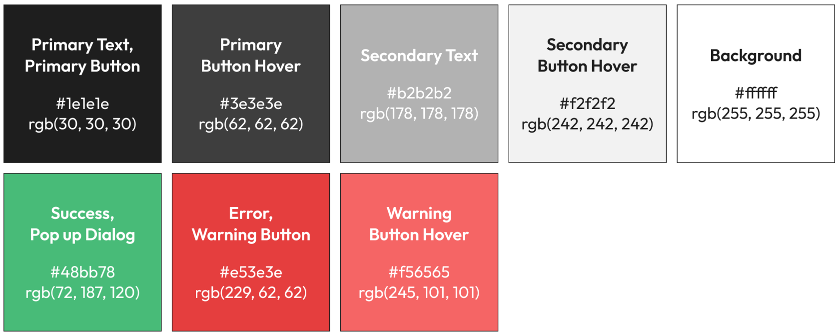

Figure 2.10: Colors used in the Neotaku configurator.

For the tool's typography, two fonts were used—the first was the typeface Outfit, as previously mentioned in the logotype in Subsection 2.5.1. The Outfit font was additionally used in titles/headers on the different pages of the Neotaku configurator and for subtitle/-body highlights and buttons. The second typeface, Noto Sans Khmer[3], was primarily used for the main body text. The hierarchy of the typefaces used in the Neotaku configurator can be seen in Figure 2.11, with specific typefaces, weights, and sizes.

Figure 2.11: Hierarchy of the two typefaces in Neotaku configurator.

3. *Noto Sans Khmer - Google Fonts* [online]. [visited on 2024-05-11]. Available from: `https://fonts.google.com/noto/specimen/Noto+Sans+Khmer`.

2.5.3 Illustrations

Multiple illustrations were added throughout the Neotaku configurator to appeal to the user and to show what is possible to create. These illustrations were 3D models created on the Neotaku website, where each illustration contained three different models from the two collections. Additionally, two models are visualized in each illustration via different materials and colors, and the third model is represented in low-poly style (see Figure 2.12).

In addition to the three model illustrations, there was a final illustration at the bottom of each page of the Neotaku website, representing the low-poly mesh of the 3D models (see Figure B.7).

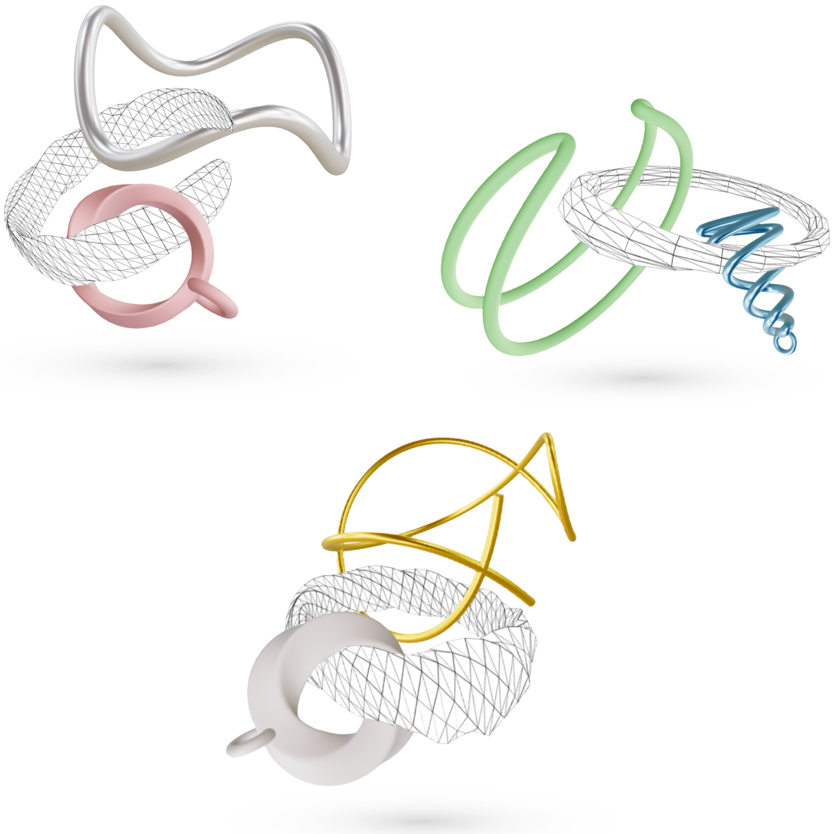

Figure 2.12: Illustrations of Neotaku 3D models.

3 Implementing Neotaku Configurator

After designing the Neotaku collections and user interface, it was time to research applicable technologies and implement the final Neotaku configurator tool. Section 3.1 defines implementation requirements for the tool in addition to the design requirements mentioned before. Then, Section 3.2 mentions technologies that were initially considered but not used, and Section 3.3 mentions final technologies. At last, Section 3.4 comments on the implementation details of the Neotaku configurator tool.

3.1 Implementation Requirements

Design requirements, as described in Section 2.1, helped design the user interface, and these requirements must also be considered in the implementation. Additionally, there are other implementation requirements to consider.

Desktop and Mobile Solution

Implementing the Neotaku configurator should consist of desktop and mobile implementation. Even though websites with product configurators offer their products mainly on desktop screens, adding a mobile option is a great way to attract potential users.

Manipulation with 3D Models

3D models in the Neotaku configurator should be easily manipulated to see the 3D visualization from various angles, where there would be no skewed view for the user to look at. Furthermore, the model's rotation should be apparent to the customer.

Instant Change of Parameters

Additionally, when a user changes a parameter in the configurator, the change should be instant so the user knows what is happening.

Because of this, the configurator should be swift and work seamlessly with the user's tool workflow.

3.2 Discarded Technologies

Many technologies initially looked suitable for the implementation, but after further research, most were unfortunately discarded.

3.2.1 Unity with 3D Modeling Software

At the start of the search for appropriate technologies, Unity[1] was considered as a base software for the product configurator due to different possibilities for working with 3D models. Even though Unity is primarily used in the game industry, it can be used in other use cases for applications, art installations, and more. Unfortunately, the pipeline of getting procedural 3D model data from several tested 3D software into Unity was cumbersome.

Blender

The first choice for the 3D software was Blender[2]. It offers multiple ways to work with 3D models—from direct modeling to sculpting. It also has a feature called Geometry Nodes[3] that is able to generate different meshes at run-time.

Unfortunately, Blender had to be discarded because no reasonable solution was available to import the 3D models with variable inputs into Unity. Unity offers an experimental meshsync[4] plugin that can emulate what is happening from Blender in Unity (even Geometry Nodes) but can not customize the parametric inputs from Blender.

1. *Unity Real-Time Development Platform | 3D, 2D, VR & AR Engine* [online]. [visited on 2023-12-10]. Available from: `https://unity.com/`.
2. *blender.org - Home of the Blender project - Free and Open 3D Creation Software* [online]. [visited on 2023-12-10]. Available from: `https://www.blender.org/`.
3. *Geometry Nodes – Blender Manual* [online]. [visited on 2023-12-10]. Available from: `https://docs.blender.org/manual/en/latest/modeling/geometry_nodes/index.html`.
4. *MeshSync* [online]. [visited on 2023-12-10]. Available from: `https://docs.unity3d.com/Packages/com.unity.meshsync@0.17/manual/index.html`.

For another solution, Blender can only export its meshes via Shape Keys[5] into Unity. However, this feature only morphs the specific mesh and can not update the mesh of a 3D model.

Grasshopper with Rhinoceros 3D

Another considered choice for the 3D modeling software was to use a program Rhinoceros 3D[6] (in short called Rhino) with an add-on editor, Grasshopper[7], commonly used to model jewelry. As a plugin, Grasshopper helps create parametric/procedural jewelry pieces via a node-based approach to the 3D models.

The data transfer of 3D models and parametric inputs between Rhino and Unity was troublesome. Rhino contains different methods to get the data through the program via Rhino Inside[8] or Rhino Compute[9]. Another solution was to serialize 3D model content into Unity via User Datagram Protocol (UDP) through network [71]. However, all mentioned solutions were either outdated or license-dependent. This software dependency meant the application could only be run on a machine with Rhino software installed.

Houdini

The third choice was to utilize Houdini[10], a 3D software primarily used for 3D modeling, VFX, and cinematography. Unlike the programs mentioned above, Houdini has a plugin integration with Unity, and developers can use Houdini aspects and features inside Unity. It also features procedural modeling, just as the other software did.

5. *Geometry Nodes – Shape Keys* [online]. [visited on 2023-12-10]. Available from: https://docs.blender.org/manual/en/latest/animation/shape_keys/index.html.
6. *Rhino | Rhinoceros | Modeling Tools for Designers* [online]. [visited on 2023-12-10]. Available from: https://www.rhino3d.com/.
7. *Grasshopper 3D* [online]. [visited on 2023-11-13]. Available from: https://www.grasshopper3d.com/.
8. *Rhino - Rhino.Inside* [online]. [visited on 2023-12-10]. Available from: https://www.rhino3d.com/features/rhino-inside/.
9. *Rhino - Compute: Features* [online]. [visited on 2023-12-10]. Available from: https://developer.rhino3d.com/guides/compute/features/.
10. *Houdini | 3D Procedural Software for Film, TV & Gamedev | SideFX* [online]. [visited on 2023-12-10]. Available from: https://www.sidefx.com/products/houdini/.

However, Houdini's procedural features do not work at the application's run-time, which discarded the option to work with parametric inputs on 3D models. Additionally, Houdini offers multiple levels of licenses, and the free license does not work as well as the paid licenses and does not support the plugin into Unity.

Substance 3D Designer

Another solution was to try Substance 3D Designer[11]. Substance 3D Designer was able to model procedural models with the help of the Substance model graphs[12]. There is also a Unity plugin for this software. Unfortunately, its procedural modeling feature was discontinued, so this option had to be discarded.

3.2.2 Other Approaches

After discarding the plan of using Unity with 3D modeling software, the goal was to find another solution relying on only one system. However, the approaches below were discarded due to missing features.

Configurator made solely in Unity

Because of all the problems mentioned above, the first choice was to explore creating a product configurator solely in Unity. Even though Unity is not primarily used for making 3D models, developers can create custom meshes through code. Unity also has plugins for procedural modeling on the Unity Asset Store. However, most feature only basic 3D models or ways to customize environments, such as Archimatix Pro[13]. After further investigation of different possibilities, this approach was discarded because it would not benefit the tool.

11. *3D design software for authoring - Adobe Substance 3D* [online]. [visited on 2023-12-10]. Available from: `https://www.adobe.com/products/substance3d-designer/`.
12. *Procedural Modeling with Designer - Adobe Substance 3D* [online]. [visited on 2023-12-10]. Available from: `https://www.adobe.com/products/substance3d/magazine/explore-procedural-modeling-with-designer/`.
13. *Archimatix Pro | Modeling | Unity Asset Store* [online]. [visited on 2023-12-10]. Available from: `https://assetstore.unity.com/packages/tools/modeling/archimatix-pro-59733/`.

Configurator made solely in Blender

The second choice was to rely solely on Blender, which offers parametric and procedural modeling features. Unfortunately, to the best of my knowledge and as of writing this thesis, there is no applicable way of using Blender to create standalone applications from its models. Nevertheless, Blender is working on a Blender Apps[14], a tool that could help the 3D models to be portable and shown to others without using any other system. This feature is now only in development but could be potentially used when fully published.

3.3 Final Choice of Technologies

As mentioned in Section 3.2, many technologies had to be discarded for various reasons, from solutions that could not release a standalone application to programs that required another license to be bought and installed. However, this research made finding the right solutions for the implementation possible.

3.3.1 Web-Based Implementation

The final decision on how to implement the product configurator was to implement it as a website. This choice was based on the technologies suitable for website product configurators. Thanks to the web-based approach, issues found in discarded technologies, such as issues with licenses or exports of 3D models from one software to another, were no longer a problem. However, because of the implementation of the website, a front-end framework had to be chosen.

React.js Front-End Framework

React.js[15], or in short, React, was chosen as the front-end framework for the website. React is a JavaScript library for building interactive user interfaces, and it is considered one of the most used front-end

14. *Blender Apps – Developer Blog* [online]. [visited on 2023-12-10]. Available from: `https://code.blender.org/2022/11/blender-apps/`.
15. *React* [online]. [visited on 2024-01-25]. Available from: `https://react.dev`.

frameworks as of 2023 [78]. React is used to develop websites containing dynamic content, which can be changed on the website, instead of developing a static website with just HTML and CSS.

There are multiple reasons why the React framework is so popular. To name a few:

- **Reusable Components:** React uses a component-based approach, which resembles the HTML tag system, enabling modular and reusable code.
- **Quick Content Refresh:** Using a Virtual DOM quickly refreshes content and handles which content should be shown on the website[16].
- **Gentle Learning Curve:** Developers familiar with JavaScript language can quickly adapt to React workflow.
- **Declarative Programming:** Thanks to the lambda expressions, declarative programming can speed up manipulating website content.

TypeScript

The development of each component and content on the product configurator website was programmed via the TypeScript programming language[17]. TypeScript was created as a superset of JavaScript that adds type checking, making it usable together with React. TypeScript is a strongly typed programming language that must be transpiled into JavaScript when the application runs. Furthermore, TypeScript's type-checking detects specific errors quickly, which makes the code less prone to errors overall.

3.3.2 Used Web-Based Technologies

Even though websites can be built with only the React framework, the Neotaku configurator needs other technologies for its functionality,

16. *Virtual DOM and Internals – React* [online]. [visited on 2024-01-25]. Available from: `https://legacy.reactjs.org/docs/faq-internals.html`.
17. *JavaScript With Syntax For Types.* [online]. [visited on 2024-01-28]. Available from: `https://www.typescriptlang.org`.

such as visualizing given 3D models, routing between pages on the website, or exporting the given mesh of the 3D model.

For React to run correctly, Node.js[18] must be added to the given project. Node.js is an open-source JavaScript run-time environment that executes code written in JavaScript and can serve the website's content. It offers the npm package manager[19] (NPM), which manages packages that may contain JS/TS code and other assets. It also automatically manages dependencies between these packages. Below, I list all npm packages used to develop the Neotaku website.

Create React App

The product configurator tool was set up thanks to the Create React App package[20]. The Create React App is an additional React package that helps configure a simple React app with one command. It also features an instant reload feature, which reloads the website content instantly when its code is saved in the editor.

Three.js via React Three Fiber

The handling of the 3D models and the parameters given to the models is provided by Three.js[21]. Three.js offers an open-source web rendering engine suitable for showing sprites, 3D models, or whole scenes with custom meshes. Additionally, it offers exports of various 3D data formats, such as .STL, .OBJ, or .glTF. Because the Neotaku configurator website used TypeScript as a programming language, the React Three Fiber[22] package was used as a React renderer for Three.js, which made it possible to use React style components in the code.

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18. *Node.js* [online]. [visited on 2024-01-28]. Available from: `https://nodejs.org/en`.
19. *npm | Home* [online]. [visited on 2024-01-28]. Available from: `https://www.npmjs.com`.
20. *Create React App* [online]. [visited on 2024-01-28]. Available from: `https://create-react-app.dev`.
21. *Three.js – JavaScript 3D Library* [online]. [visited on 2024-01-25]. Available from: `https://threejs.org/`.
22. *@react-three/fiber* [online]. [visited on 2024-05-14]. Available from: `https://www.npmjs.com/package/@react-three/fiber`.

React Three Drei

React Three Drei[23] is an additional package that works with the Three.js and React Three Fiber. This package helps with additional abstract components that can be used to visualize the 3D models, such as setting lights for a scene or controls via which the model moves with the user input.

Chakra UI

Chakra UI[24] is a package with ready-made modular UI components that can be used to build a website quickly. It offers various components for inputs, media, data, navigation, or forms.

React Router DOM

A multipage React website needs a router to address changes in the website to work properly. React Router DOM[25] ensures the content is displayed correctly when the user navigates to a new page. It also updates the browser's current URL accordingly.

3.4 Implementation Details

The Neotaku configurator was implemented with easily reusable components to speed up the implementation process. Additionally, at the start of the implementation, it was crucial to define the structure of the components and the site's layout. The implementation's source code can be found in Appendix A in the `neotaku-website.zip` file.

3.4.1 Project Structure

React projects can be structured in several ways. For the Neotaku configurator, all components like pages, subpages, jewelry collections,

23. *@react-three/drei* [online]. [visited on 2024-05-14]. Available from: `https://www.npmjs.com/package/@react-three/drei/v/9.0.1`.
24. *Chakra UI: Simple, Modular and Accessible UI Components for your React Applications* [online]. [visited on 2024-01-28]. Available from: `https://chakra-ui.com`.
25. *React Router* [online]. [visited on 2024-01-28]. Available from: `https://reactrouter.com`.

and jewelry data are located in the src folder. Additionally, images such as backgrounds, illustrations, jewelry mockups, and logotypes with icons are located in the public/images folder.

The src folder has a structure of multiple folders for different logical parts of the tool. At the root of this folder, index.tsx and theme.ts are located. Subfolders located in the src folder are divided into three folders: components, pages, and subpages, which contain the rest of the project implementation. The hierarchy of the src folder can be seen in Figure B.8.

3.4.2 Components

As described in Subsection 3.4.1, the src folder contains multiple files and folders containing other necessary components for the tool to work. Listed here are the main components, their features, and their usage of other components.

Index

Component index located at the root of the src folder contains the root rendering of the application, with the definition of the router as well. It is the main component of the application that enables it to run.

Theme

Component theme, also located at the root of the src folder, contains the definitions of colors, fonts, and text styles for the Chakra UI components used in the tool. This theme is then used in the index to wrap the application's router so that the Chakra UI style is applied to all components in the project.

WebsiteLayout

For the website layout, the component WebsiteLayout was created. This component creates a skeleton for all pages on the website, where each page includes MainMenu, Outlet from the React Router where the change of content happens, and Image from Chakra UI displaying the illustration at the bottom of pages with the Footer component.

Collections

The `Collections` component has predefined presets for the Lissaje and Torsion collections, where each collection contains four jewelry types: ring, bracelet, earring, and pendant. In this component, each piece of jewelry has metadata about the collection it is from, the parameters that change the jewelry's design, and the description shown when the given jewelry is selected for configuration. Additionally, it contains a rendering function that takes all given jewelry parameters and renders them as UI inputs via the `LissajousCollection` or `TorsionCollection` component. `LissajousCollection` and as well as `TorsionCollection` components contain the definitions of the four jewelry types in the given collection.

HomePage

For the page components, `HomePage` contains a preface about the website with the Neotaku logo, presets of three jewelry types, and a contact section. The three mentioned presets redirect the user to the `ConfiguratorPage` for a quick "try-on" of the configurator. This component also contains the `Contacts` component at the bottom of the page, which describes some other information about the tool.

CreatePage

Component `CreatePage` showcases presets that the user can choose and customize further on the `ConfiguratorPage`. When a user clicks on the given preset, the `ConfiguratorPage` obtains a URL containing encoded Base64 parameters in JSON format, and the page decodes the given information. Additionally, `CreatePage` contains a `TabList`, a Chakra UI component that switches between the four jewelry types. When selecting a specific tab, the `TabPanels` Chakra UI component shows the given jewelry type in Lissaje and Torsion collection.

ConfiguratorPage

The most significant and crucial component is `ConfiguratorPage`. It is divided into smaller components corresponding to the page's features.

Firstly, the component decodes the URL from Base64 with data in JSON format. The data contains information about what jewelry to show and all jewelry attributes (see Figure B.9). Then, these parameters are read via subpage components like `General`, `Collection`, `Visualize`, and `Finalize`, so each parameter, material, color, and price are correctly set up. Furthermore, these parameters are given to the `RenderCanvas` component, which renders the given jewelry with its attributes. The process of setting up new parameters is repeated when some parameter is changed on the website in order to update it.

`ConfiguratorPage` also contains a short description of the jewelry from the `Info` component, and the `GoBack` component provides a redirect to `CreatePage`. Saving of the 3D data and copying the URL of the jewelry happens in the `Finalize` component, where the jewelry 3D model can be exported in .STL, .OBJ, or .glTF, and the JSON file of the updated parameters are encoded into Base64.

AboutPage

`AboutPage` mainly contains information about the website, what it is for , and what the user can customize. Additionally, a `Contacts` subpage is included.

LookbookPage

`LookPage` shows all presets from `CreatePage` on one page to showcase what is possible to create in the Neotaku configurator. When a user clicks on a given preset, just as in `CreatePage`, the user is redirected to `ConfiguratorPage`.

NotFoundPage

`NotFoundPage` shows a text message to the user that the page they wanted to see does not exist, which can happen when the URL is in an incorrect format.

4 Testing Neotaku Configurator

After implementing the Neotaku configurator, it was necessary to test the website interface and gain feedback from the target audience. This chapter describes the whole process of the user study, from the gathering of the research methods (see Section 4.1), recruiting participants (see Section 4.2), and the testing of the qualitative user study with its findings (see Section 4.3 and Section 4.4). Finally, Section 4.5 summarizes the qualitative user study of the Neotaku configurator. The whole structure of the qualitative user study can be found in Appendix A, within the `user-study.zip` file.

4.1 Research Methods

In order to test the user interface of the Neotaku configurator and monitor the user's experience while using it, specific research methods had to be chosen.

After researching potential methods that could benefit the user study, the first important method to use was the Usability Testing method [88]. This method is used to identify problems, gain insight into what people want, and learn more about how people use a product. Additionally, to gain more information about participants' preferences, the research included qualitative research methods, such as one-on-one interviews, and quantitative research methods, such as questionnaires about the product's usability. The qualitative user study was structured into five parts.

4.1.1 Introductory Interview

The first part of the user study was to gain qualitative information about the participant's preferences in three categories: configurators, shopping habits, and 3D printing. Questions from the interview were concerned with what product configurators are, whether participants know their shopping spending habits, whether they are willing to pay more for a customized product, and forming their thoughts on 3D printing in general.

4.1.2 First Look at Neotaku Configurator

The second part of the user study introduced the Neotaku configurator tool to the participants. Participants were asked to examine the tool to gain experience thoroughly, and after that, they were asked to create custom jewelry. This task had no restrictions on the final jewelry's appearance; it was purely subjective, based on what participants would find appealing. Throughout this process, participants could ask questions if they had any.

4.1.3 Usability Tasks

After the introductory interview and first use of the configurator, participants were given three usability tasks, representing scenarios that could happen when using the configurator tool. Participants were asked to use the think-out-loud method [89] and try to complete the tasks without help as each task simulated a possible real scenario. After each task was completed, participants were asked multiple questions concerning the task's difficulty. Among them was a Single Ease Question (SEQ) [90] with a 7-point scale where 1 was interpreted as a challenging task and 7 was an easy task. Other questions included after the tasks were regarding the used jewelry parameters.

1st Task - Customization Task

The first task was ring customization, where participants had to change the parameters mentioned in the scenario. Participants had much freedom when designing the potential ring for a friend, as it was the first and most straightforward scenario. After customizing, they had to save the finalized 3D model onto the computer as an .STL file. The purpose of the task was to see if they understood the jewelry properties correctly and if they knew how to save the given 3D model.

2nd Task - Replication Task

The second task was a replication task, which consisted of replicating a screenshot of a 3D model from the Neotaku configurator. Participants only knew about the jewelry type, which was earrings. The primary purpose of this task was to see if participants correctly understood the parameter properties and if they could easily recreate the given screenshot. After successful replication, participants had to know how to send a jewelry share link to a friend. Furthermore, parameters changing the mesh dimensions, like height or width, were not considered because they were insignificant in this scenario.

3rd Task - Optimization Task

The third and final usability task was about price optimization. Participants were given a link from the Neotaku configurator, which included a customized bracelet. The task for the participants was to find out if the given bracelet could be cheaper when the bracelet's material was metal, and the fictional company had 3D printing restrictions for printing with metal. Even though the displayed price in the configurator was only a mere approximation of the final price for the bracelet, this task was included so that the participants could realize which parameters change the price the most in the configurator.

4.1.4 Quantitative Questionnaire

After the three usability tasks, the participants were given a questionnaire about their overall user experience throughout the testing process. The questionnaire consisted of a Net Promoter Score (NPS) question [91], measured on a scale from 0 to 10 for how likely the participant is to recommend a given product to others, with zero being not likely and ten being extremely likely. Additionally, the questionnaire had a section of questions inspired by the Post-Study System Usability Questionnaire (PSSUQ), which suited the purposes of the study [90]. Each question was tailored to the usage of the Neotaku configurator tool and had a 5-point scale from strongly agree to strongly disagree. One question from the original PSSUQ regarding the system's error notices was not included because it was unsuitable for this study.

4.1.5 Debrief

After the questionnaire section, the debriefing interview began. The participants were asked questions that summarized their whole experience with the Neotaku configurator tool, as well as highlights and drawbacks of the tool as well. The questions followed the pattern of the PSSUQ-inspired questions to gain more qualitative feedback from the participants. Additionally, the debrief included a question asking what else the participants would expect from the tool and the most intriguing part of the scenarios/study for the participants.

4.2 Recruiting Participants

While preparing the research methods for the user study, it was also necessary to find suitable participants. As the Neotaku configurator is a creative way of customizing given jewelry, this tool's target audience can be broad. However, for the user study, I decided to address young respondents with some experience in creative fields, such as painting, photography, sewing, and others. The logic behind this decision is that the creativity trait can help them navigate the Neotaku configurator. Additionally, these respondents may have interesting qualitative feedback that could be used when designing new features and additions to the configurator.

The respondents were addressed directly through various social platforms, with the condition that if they wanted to participate, they should engage in creative tasks or handicrafts, whether in their free time or at work.

4.3 Qualitative User Study

After picking suitable research methods, creating the structure of the qualitative user study, and finding the participants for the user study, the testing could begin.

4.3.1 Testing Details

The testing of all participants took place in the Human-Computer Interaction (HCI) Lab[1] at the Faculty of Informatics of Masaryk University. HCI Lab was chosen because participants would have the

1. *HCI – Human-Computer Interaction Laboratory* [online]. [visited on 2024-05-06]. Available from: `https://hci.fi.muni.cz`.

same testing conditions without distractions. The user study tested the Neotaku website in the desktop form, and the user study was to last around 60 minutes for each session. The testing was done on the deployed Neotaku website, whose URL can be found in Appendix A in the `neotaku-deployed-website` shortcut link.

4.3.2 Participants

Overall, there were 15 participants in the qualitative user study. The participants were aged from 20 to 27 years, and the most prominent age group was 23 to 25 with 8 participants. 10 out of the 15 participants were females, and 5 were males. Eleven respondents studied computer science, specifically Visual Informatics (Graphic Design, Game Development), Computer Systems, Management of Software Systems, or Informatics in general. The other four respondents studied fields related to biology (Biostatistics, Biomedical Technology), psychology, and dentistry. Additionally, eleven participants from the study work in the field they had studied for.

What unites all of the participants is their creativity in various forms. Traditional art forms such as painting, drawing, and handicrafts were described by twelve participants. Other art forms like photography, video recording, 3D modeling, and cosplay creation were mentioned by seven participants acquainted with the classical art form. Furthermore, the other three participants express themselves in other unique forms through dancing, game design, or origami.

Each participant was tested on one laptop that recorded their voice and screen, while I also took written notes for each session. Additionally, each participant was instructed about what to expect before the user study, and each research method was explained to them beforehand. After the user study introduction, the participants signed a consent form about anonymizing and using their data.

4.4 Findings

After gathering the data from all 15 participants, it was time to analyze them. Each participant's response was categorized based on the user study structure for more straightforward data analysis.

4.4.1 Introductory Interview

The user study began with an introductory interview, which included questions regarding product configurators, participant's shopping habits, and 3D printing.

Product Configurators

At the start of the interview, participants had to describe the definition of a product configurator. All 15 participants knew some definition of a product configurator and could describe it. Additionally, eight participants shared their experience of various product configurators—three participants mentioned configurators for furniture or electronics, three others mentioned shoe configurators, and finally, the last two mentioned configurators for presents like mugs or shirts. For the question of whether they liked or disliked the mentioned configurators, two participants who mentioned the furniture configurators shared that they enjoyed the realism of the 3D visualization. However, these two participants also mentioned that they did not enjoy not being able to rotate the product or not being able to choose what they wanted to customize.

Shopping Habits

The following questions were regarding the participant's shopping habits. For the question about how often participants shop, eight participants said around one time per month. The other seven participants shop around one time per three months, or they shop from time to time. Regarding jewelry shopping, only eight participants buy jewelry regularly, and the rest do not buy jewelry because they already own enough of it or do not want to wear it. When it comes to shopping online or offline, almost all participants prefer the combination of both except three. Additionally, when participants shop online, almost all participants prefer desktops or laptops because of the bigger screen.

Online Shopping and Unique Pieces

The other questions concerned the topic of online shopping and the preferences for unique product pieces. Ten respondents commented that when they bought a product online, it did not fit. The majority of the participants said that it was because of the wrong measurements from a website. Other participants commented that their fault could have been the cause of the wrong measurements.

After the questions about the problem regarding online shopping, participants were asked if they had any unique or tailored pieces. Eight participants said they owned something unique, and the reasons they owned it were various, from being different from others to helping sustainable and small brands. When the participants were asked if they would pay more for a customized product specifically for them, the majority would pay more, but it would depend on how much the product's final price would go up.

3D Printing

The last questions for the introductory interview were about 3D printing. Six participants owned a 3D printer at home; the other nine did not own the 3D printer, but six had some experience with it. The three participants without experience with 3D printing commented that they would like to try it someday.

Participants were also asked what they could imagine as the benefits or drawbacks of 3D printing. Regarding the benefits, most participants said that they can create whatever they want/need and that 3D printing is beneficial for fixing minor issues in the household. Additionally, one participant mentioned the usage of 3D printed implants in the medical field. However, the drawbacks that the participants mentioned included the price of 3D printers and 3D printed products, the fragility of the material, and the waste that comes with prototyping.

4.4.2 First Look at Neotaku Configurator

After the introductory interview, participants were asked to try the website for the first time and create something they would like. All participants were able to navigate through the website without any significant issues, and they were able to create their own customized jewelry. Throughout the jewelry creation, some of the participants had ideas on how to change some features on the website—these features are mentioned and discussed in Subsection 4.4.4 with the final remarks of the participants.

4.4.3 Usability Tasks

The next step in the user study was for the participants to complete three usability tasks. All participants were able to complete the tasks, but some tasks were more challenging for participants than others.

1st Task - Customization Task

The first task about the ring customization was the easiest, based on the SEQ provided right after the task. Eight participants scored this task 7, while the others gave this task a 6 (see Figure 4.1). These scores show that the participants found the task easy to perform. Additionally, the completion time for this task ranged from 1 minute to 4.33 minutes, with an average of around 2.27 minutes.

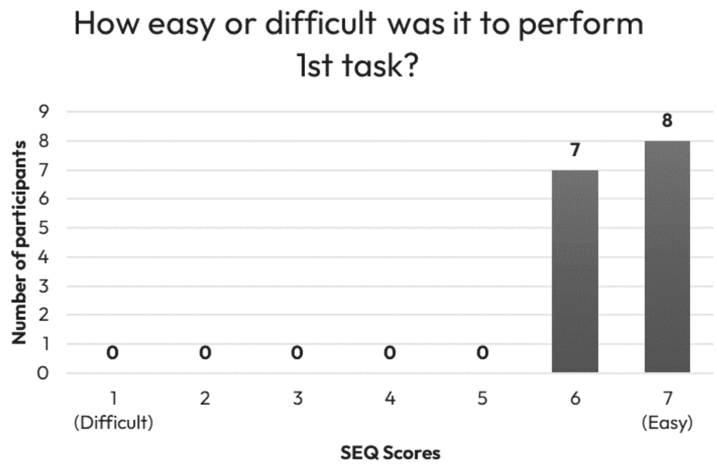

Figure 4.1: Frequency distribution of SEQ scores for the 1st task.

After completing the task, participants made some comments supporting this SEQ feedback. Overall, each participant said that they understood the parameters used in this task and could complete it without significant issues. Some minor problems that occurred were problems with the English names of the jewelry, such as the word 'pendant'. Another issue that possibly lowered the score for this task was the 'Save 3D Model' button—three participants did not know what to expect when clicking on this button.

2nd Task - Replication Task

The second task for the participants was to replicate a screenshot of jewelry from the configurator. This task had mixed reviews after the completion, even though all participants were able to complete it. Based on the SEQ provided right after the task, the scores ranged from 2 (hard) to 7 (very easy), with 4 and 5 being the most chosen values for this task (see Figure 4.2). The completion time ranged from 1 minute to 7 minutes, with an average of around 3.1 minutes.

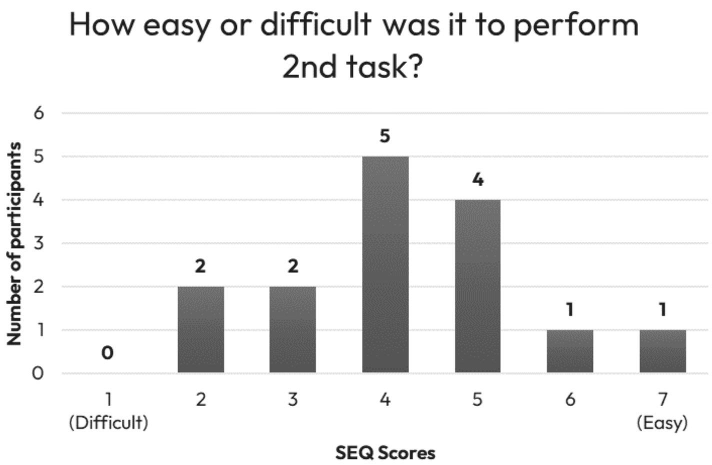

Figure 4.2: Frequency distribution of SEQ scores for the 2nd task.

Participants commented on several reasons of why this task was more challenging than the first one. Because the task was aimed at the Torsion collection, there were parameters for the mesh twisting. Three participants mentioned that they did not expect the 'Twist' parameter to go into negative values, and six participants did not fully understand how the 'Twist All' switch works or did not realize they could change the option. Additionally, two participants mentioned that they were surprised that there are different configurator properties between collections.

3rd Task - Optimization Task

The third and final usability task was to optimize the price for a metal bracelet on the configurator page. This task was more straightforward than the replication task but still more complex than the customization task. For this task, six participants gave the task a score of 5, and other participants distributed their scores around the 3, 6, and 7 values (see Figure 4.3). The completion time for this task ranged from 1 minute to 6.5 minutes, with an average of around 2.63 minutes.

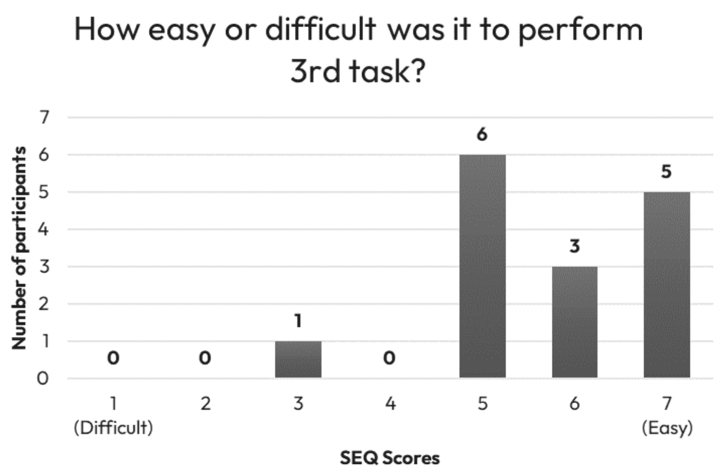

Figure 4.3: Frequency distribution of SEQ scores for the 3rd task.

The participants made no comments to help explain this task's SEQ score. Each participant knew what the parameters were for , and that they could lower the price thanks to the 'Height' parameter. Almost half of the participants first tried all the parameters to ensure they knew how given parameters worked and to see if they had changed the product's price. After the task, one of the participants mentioned that they would appreciate it if there was some indication of what parameters change the price of the jewelry.

4.4.4 Quantitative Questionnaire and Final Debrief

After completing the usability tasks, participants were asked to fill in a questionnaire inspired by fifteen questions from the PSSUQ questionnaire and one NPS question. The quantitative questionnaire is connected with the debrief section to analyze the questionnaire answers with the participants' responses qualitatively. Additionally, each category contains figures summarizing participants' responses to the questions via frequency analysis.

System Usefulness

Q1: Overall, I am satisfied with how easy it is to use this system.

13 of the participants strongly agreed with this statement. The other two participants only partially agreed or were neutral to this statement. The average score for Q1 was around 1.20. Participants also commented on this fact in the final debrief interview as well.

Q2: It was simple to use this system.

12 of the participants strongly agreed, 2 agreed, and one was neutral to this question. The average score for Q2 was around 1.27. Some participants also commented on the system's simplicity in the final debrief.

Q3: I was able to complete the tasks and scenarios quickly using this system.

8 of the participants strongly agreed, 5 participants agreed, and 2 participants were neutral to this statement. The average score for Q3 was around 1.60. This score corresponds with the analysis of the usability tasks above in Subsection 4.4.3, where participants had some problems with the tasks.

Q4: I felt comfortable using this system.

13 participants strongly agreed with this statement, and 2 participants agreed. The average score for Q4 was around 1.13. Throughout the testing session, none of the participants had any issues regarding the convenience of the configurator.

Q5: It was easy to learn to use this system.

Again, 13 participants strongly agreed with this statement, and 2 participants agreed. The average score was around 1.13. Each participant said in the final debrief that the system was simple and easy.

Q6: I believe I could become productive quickly using this system.

8 participants strongly agreed, and 7 participants agreed with this statement. The average score was around 1.47. The score can be backed up by completion times in the tasks, which had significant ranges between the participants.

To summarize results for the System Usefulness category, participants found the system easy and natural to use. However, participants took more time than I expected. To visually represent these findings, Figure 4.4 shows how participants answered each question.

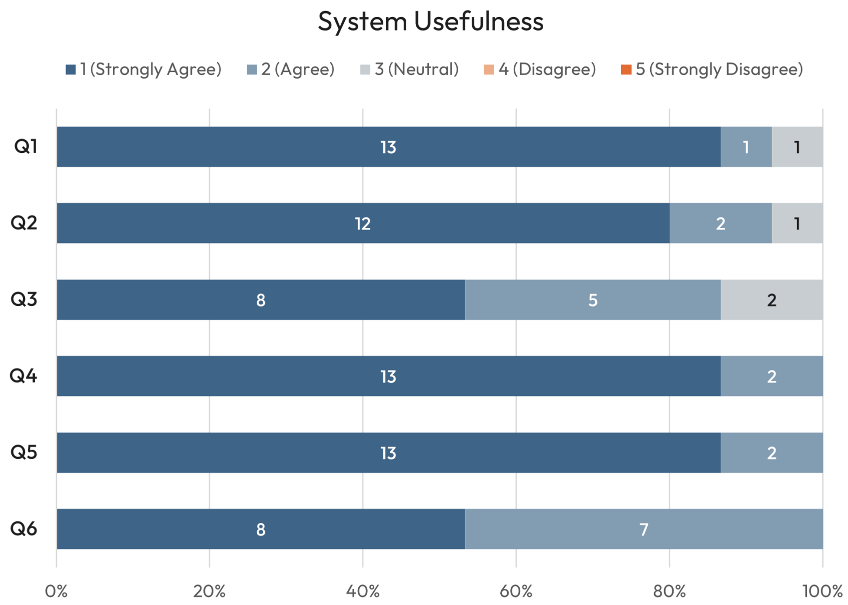

Figure 4.4: User satisfaction ratings for System Usefulness category.

Information Quality

Q7: Whenever I made a mistake using the system, I could recover easily and quickly.

5 participants strongly agreed, 6 agreed, and 4 had neutral scores for the statement. The average score for Q7 was around 1.93. There were various reasons why this score was lower than the previous ones in the first category. For example, two participants mentioned the inability to 'undo' an action in the configurator, which could lead to mishaps during the customization. Additionally, five participants mentioned that they needed clarification as to why they could change the jewelry type of already clicked jewelry because when they returned to the previous jewelry type, there was no progress on the product.

Q8: The information (like online help, on-screen messages, or other documentation) provided with this system was clear.

7 participants strongly agreed, 5 agreed, and 3 were neutral with this statement. The average score for Q8 was 1.73. Throughout the testing, participants mentioned some thoughts about the configurator's features that they needed clarification on, such as the length of the text on the page mentioned by four participants or needing help understanding every parameter or word used in the configurator mentioned by two participants.

Q9: It was easy to find the information I needed.

11 participants strongly agreed, 3 agreed, and 1 remained neutral with this statement. The average score for Q9 was around 1.33. What potentially explains this score is that three participants commented that the finalize section of the configurator should be visible at all times for easier information tracking.

Q10: The information was effective in helping me complete the tasks and scenarios.

12 participants strongly agreed, and 3 agreed with this statement. The average score for Q10 was around 1.20. Participants were mostly content with the information provided to them throughout the tasks—multiple participants mentioned that

they liked how the configurator page had only one screen. Because of this, every parameter was easily and quickly accessible.

Q11: The organization of information on the system screens was clear.

8 participants strongly agreed, and 7 agreed with this statement. The average score for Q11 was around 1.47. This score could be lower because of the same problem with the finalize section, as mentioned in Q9. Additionally, two participants commented that the showcase page could be more structured, and two other participants said that they did not expect to be redirected to the jewelry configurator when clicking on a specific image.

Based on the responses, participants could quickly and effectively use the information they wanted based on the Information Quality category. However, there were some problems regarding the structure of the given information, and not all information was perfectly understandable to the participants. Figure 4.5 shows the summary of how participants answered each question in this category.

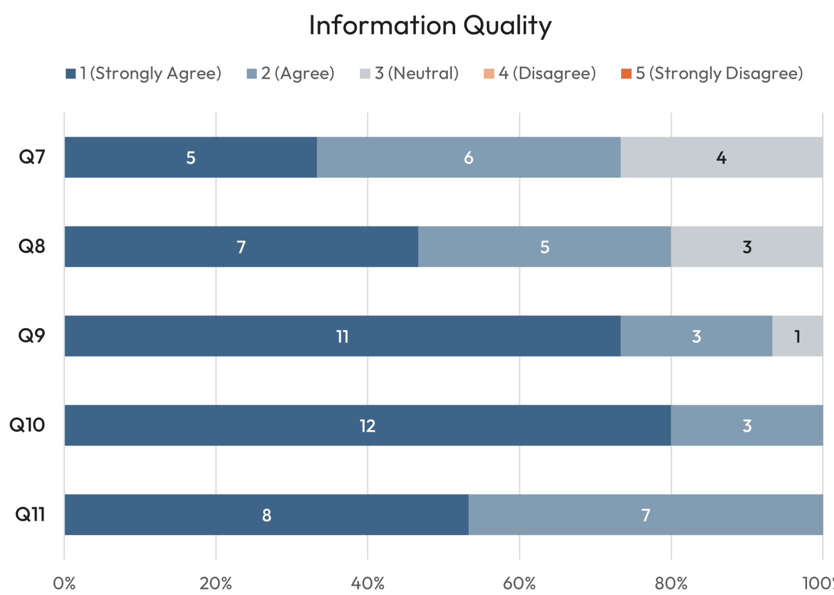

Figure 4.5: User satisfaction ratings for Information Quality category.

Interface Quality

Q12: The interface of this system was pleasant.

13 participants strongly agreed, and 2 participants agreed with this statement. The average score for Q12 was around 1.13. Throughout the testing session, each participant commented that they liked the simplicity and ease of the interface.

Q13: I liked using the interface of this system.

12 participants strongly agreed, and 3 participants agreed with this statement. The average score for Q13 was around 1.20. All participants mentioned this fact when completing the three usability tasks.

Q14: This system has all the functions and capabilities I expect it to have.

5 participants strongly agreed, 7 participants agreed, 1 participant remained neutral, and 2 disagreed with this statement. The average score for Q14 was around 2.00. Even though participants liked the simplicity of the design and interface, they mentioned many features that the configurator did not have, such as:

- more colors and materials requested by five participants,
- more designs to choose from requested by five participants,
- being able to save jewelry models on the website requested by three participants,
- being able to see the jewelry model on a photography or a mockup as requested by three participants,
- information about where to 3D print given models requested by four participants,
- information on how to measure properly the size of the rings and bracelets requested by three participants.

To sum up the Interface Quality category, participants enjoyed the system's interface, but they would like to see more features. However, some of the mentioned features can have unwanted side effects, such as privacy policy concerns when the system lets users create accounts. All summarized answers of participants from this category can be seen in Figure 4.6.

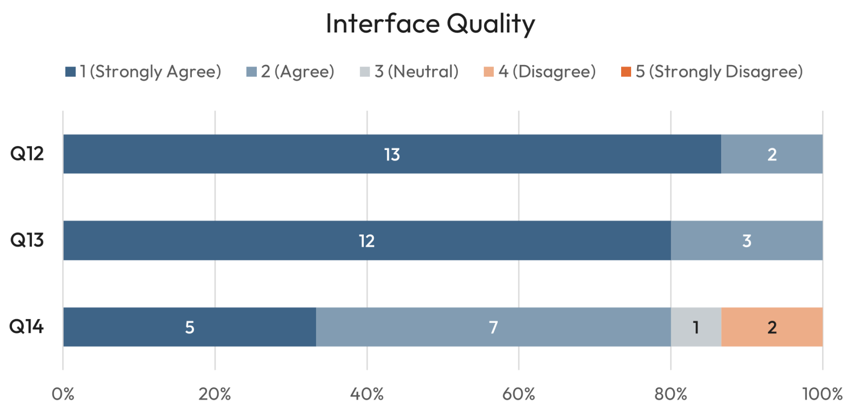

Figure 4.6: User satisfaction ratings for Interface Quality category.

Overall Satisfaction

Q15: Overall, I am satisfied with this system.

12 participants strongly agreed, and 3 participants agreed to this statement. The average score for Q15 was around 1.20. All participants mentioned in the final debrief that they were satisfied with the system.

Participants were satisfied with the system for the Overall Satisfaction category and had no other comments to add. Figure 4.7 shows the overall satisfaction of participants.

After the PSSUQ-inspired questions, the final NPS question for the participants was to answer if they would recommend the tool to others. To compute the final score for the NPS question, the participants' responses were divided into three customer types: promoters, passives, and detractors.

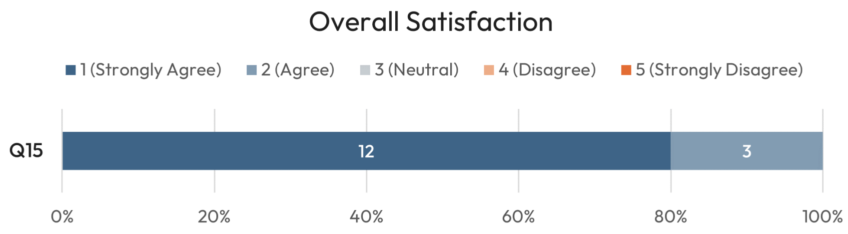

Figure 4.7: User satisfaction ratings for Overall Satisfaction category.

Net Promoter Score

NPS: How likely are you to recommend this website to a friend or a colleague?

Promoters (scores 9 and 10): 10 participants agreed with scores 9 and 10, with five participants giving a score of 9 and five participants giving a score of 10.

Passives (scores 7 and 8): 4 participants agreed with scores 7 and 8, with two participants giving a score of 7 and two participants giving a score of 8.

Detractors (scores from 0 to 6): Only 1 participant agreed with a score from 0 to 6 while giving a score of 3.

The distribution of promoters, passives, and detractors can be seen in Figure 4.8.

After looking at participants' responses to PSSUQ-inspired questions and NPS question, there is no crucial indicator as to why some participants chose the scores of 7 and 8 instead of 9 and 10 for the NPS question. However, some participants at the start of the user study stated that they do not wear jewelry. Additionally, the detractor participant who chose the score of 3 probably misinterpreted the question because their qualitative and quantitative feedback was positive and contained no significant comment for the system.

The percentages for promoters and detractors can be calculated based on the values of each category of promoters, passives, and detractors. The final NPS score is then calculated by subtracting the detractor rate from the promoter rate.

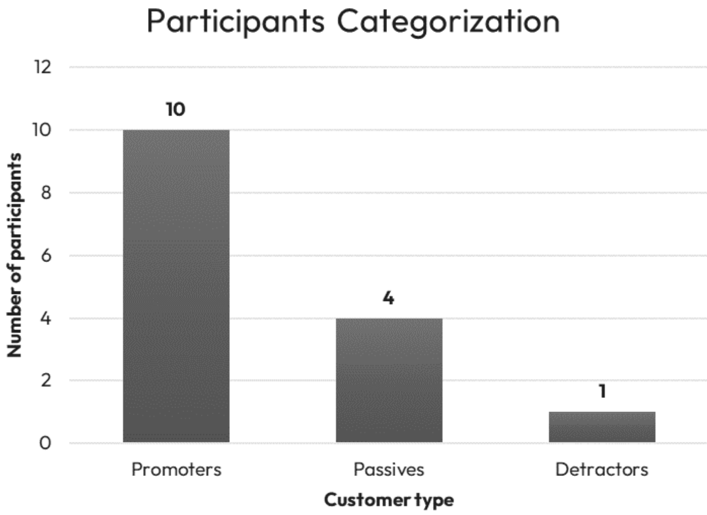

Figure 4.8: Frequency distribution of participants into promoters, passives, and detractors for NPS question.

Percentage of promoters

$$\frac{\text{number of promoters}}{\text{total participants}} \times 100 = \frac{10}{15} \times 100 = 66.67\%$$

Percentage of detractors

$$\frac{\text{number of detractors}}{\text{total participants}} \times 100 = \frac{1}{15} \times 100 = 6.67\%$$

Final NPS Score

$$\text{promoter rate} - \text{detractor rate} = 66.67\% - 6.67\% = 60$$

The final NPS score of 60 is excellent. However, it must be considered that the configurator was tested only on 15 participants. On the other hand, the selected 15 participants were content with the website itself, and even though there were some issues regarding the Information and Interface Quality categories from the PSSUQ-inspired questions, they would still recommend the system to others.

4.5 Final Remarks

Finally, the final verdict from the qualitative user study had to be concluded. Overall, participants had a pleasant user experience with the Neotaku configurator while using its user interface.

Throughout the user study, most participants commented that they enjoyed how simple, easy, and fun it was to use the configurator. The main keywords they described at the end of the study were simplicity, uniqueness of created jewelry pieces, nice visualizations of jewelry, and aesthetic-like interface. Four participants even thought the website offered the 3D product as an established brand, not just as a 3D visualizer. The in-depth interviews and questionnaires allowed participants to express these feelings in quantitative and qualitative form.

Additionally, throughout the testing sessions, some minor bugs were discovered. In three sessions, the participant found a bug when clicking on the configurator page, where the material type was not correctly set up. After tracking down the problem in the code, the bug was fixed and has not been encountered since. Every participant who experienced a bug throughout testing was immediately notified by me about the unexpected problem.

Participants also mentioned feedback that could benefit the tool's next iteration. Four participants mentioned they were too lazy to read all the text on the website, which could lead to unexpected outcomes. Furthermore, one participant mentioned that rather than reading the labels on the configurator page, it was much easier for them to try out all parameters that could be changed and then change them how they would like. Nevertheless, some configurator features should have more precise labels for participants who read the parameter names, such as the 'Twist All' parameter or the 'Copy Configuration' button. Besides the amount of text, some participants also mentioned that they would categorize the showcase page of the website as well as highlight the differences in the configurators for the Lissaje and Torsion collections. Additionally, the option to choose a jewelry type in the configurator should leave the jewelry state when clicked on another jewelry type, or it should be removed.

For the following additions to the tool, participants had many ideas about what they would like to have in the Neotaku configurator. Four participants commented that they would like to have more collections to choose from and more designs overall. For the configurator page, five participants mentioned that it would help them if there were photos of the product on a person or some viewer for the customized jewelry. Finally, three participants would like a tutorial on measuring the correct sizes for the rings and bracelets and a page after the configuration process for the next steps on where to go to 3D print/cast given 3D model.

To sum up, the Neotaku configurator was a pleasant experience for participants in creating customized 3D models for 3D printing, and the user interface was simple yet effective in the testing process. Furthermore, participants provided beneficial feedback for the website that could be used in the next update.

5 Expert Evaluation of Neotaku Configurator and Its 3D Prints

After the qualitative user study of the Neotaku configurator interface, it was necessary to test how the jewelry would look like when 3D printed. Because of this, an expert evaluation was needed to obtain a final verdict about the Neotaku configurator website and the 3D prints. Section 5.1 describes the choice of which Neotaku models to 3D print and their outcomes from the 3D printers. Then, Section 5.2 introduces a jewelry expert who evaluated the website and the final 3D prints. At the end of the chapter, Section 5.3 mentions final remarks about the 3D prints and the Neotaku website.

5.1 Neotaku Configurator 3D Prints

Because there are many jewelry possibilities that the Neotaku configurator can create, a plan had to be made for what would be 3D printed. Furthermore, to obtain various results, the search for 3D printers that could be used for testing began.

5.1.1 Choosing What To 3D Print

For the testing of the 3D prints, the plan was to test each jewelry type on several brands of 3D printers, where two models were from the Lissaje collection, and the other two were from the Torsion collection. A ring and a pair of earrings were chosen from the Lissaje Collection, and a bracelet with a pendant were chosen from the Torsion Collection. Each piece of jewelry was created using the various parameters that the Neotaku configurator offers. The 3D models for the ring and bracelet were customized to fit smaller hands. These four jewelry pieces were printed using two FDM printers and one SLA 3D printer.

Additionally, to test the Neotaku configurator with the metal materials, another ring model from the Lissajous collection was sent to the company Allure[1], which creates customizable jewelry from metals via

1. *Allure - Probably the best jewellery* [online]. [visited on 2024-05-14]. Available from: `https://www.allure.cz`.

the lost wax casting method and special drop-on-demand 3D printers. Prior to the ring's 3D printing and metal casting, it was thoroughly discussed with Radovan Grmuša from this company.

The five 3D models were downloaded as .STL files from the Neotaku website and the models were already sized in millimeters. The mentioned models chosen to 3D print are in Appendix A in the `neotaku-3d-models.zip` file.

5.1.2 Final 3D Prints

Two FDM printers and one SLA printer were chosen to test print the models. For the metal ring model of the ring, as the process is lengthier than 3D printing on FDM or SLA, the final model has not yet been finished at the writing of this thesis, but the creation process is described.

1st FDM 3D Printer - Creality Ender-3 Pro

The first 3D printed models were from the FDM printer called Creality Ender-3 Pro[2]. This 3D printer is a cost-available 3D printer to the general public, which can generate various results based on the prepared 3D printer settings. The primary important setting for the Neotaku 3D prints was the layer height in millimeters. For this 3D printer, the minimal size that could be achieved was 0.16 mm, and the material used was a PLA filament.

The final 3D prints from this 3D printer can be seen in Figure 5.1. At first look, it was evident that this 3D printer could not produce high-quality 3D prints with small details. Some features, like the small rings used as hooks for the jewelry, were not even printed because the layer height of the 3D printer was not small enough. The 3D printer had trouble in the upper part of the earrings, where the deposition nozzle could not complete it. Additionally, the bottom part of the jewelry got stuck to the 3D printer's bed, which created an uneven surface on the jewelry, and the supporting structures created some artifacts that had to be sanded down in the post-process.

2. *Ender-3 Pro 3D Printer* [online]. [visited on 2024-05-14]. Available from: `https://www.creality.com/products/ender-3-pro-3d-printer`.

Figure 5.1: 3D prints from the Creality Ender-3 Pro.

2nd FDM 3D Printer - Stratasys Fortus 250mc

The second FDM printer was a 3D printer called Stratasys Fortus 250mc[3], a commercially used FDM printer. For the Neotaku 3D prints, the layer height for the given model could go much lower than the first 3D printer, where the layer height could be set to 0.178 mm, the lowest layer height possible on this 3D printer. Furthermore, the 3D printer used an ABS Plus filament as a material.

The final 3D print from the Stratasys printer can be seen in Figure 5.2. Even though the layer height is bigger than on the Creality 3D printer, the results look more polished and ready without any more post-processing besides removing the support structures. The earrings and pendant hooks were successfully created, but some stringing occurred in some parts of the 3D prints.

3. *Fortus 250mc 3D Printer | Stratasys* [online]. [visited on 2024-05-14]. Available from: `https://support.stratasys.com/en/Printers/FDM-Legacy/Fortus-250mc`.

Figure 5.2: 3D prints from the Stratasys Fortus 250mc.

SLA 3D Printer - Anycubic Photon S

For the SLA 3D printer, the Anycubic Photon S[4] was used with a clear UV-sensitive liquid resin. Thanks to the SLA method, the layer height for the Neotaku 3D prints was set at 0.05 mm, much lower than in the FDM printers.

The final 3D prints from the Anycubic printer can be seen in Figure 5.3. This SLA printing technique has the most detail of all the options. All jewelry models were correctly printed with high detail, and the hooks on the pendant and earrings were correctly printed out. However, the pendant's size had to be doubled because it crumbled after its first printing and UV curing. This crumbling was caused by the pendant's small size for the liquid resin to hold.

Drop-On-Demand 3D Printer - Solidscape S350

To create the metal ring, I was introduced to Allure's drop-on-demand 3D printers, which are used with the traditional lost wax casting

4. *Anycubic Photon S* [online]. [visited on 2024-05-14]. Available from: `https://store.anycubic.com/products/anycubic-photon-s`.

Figure 5.3: 3D prints from the Anycubic Photon S.

method to achieve the most detailed jewelry pieces with the help of 3D printing methods.

The process starts with a 3D printing of the jewelry on a drop-on-demand Solidscape S350[5] 3D printer, which works with wax in order to build up a wax model of given jewelry with a high level of detail, where the thickness of the layer can be small down to 0.00635 millimeters. This 3D printing process has made the traditional jewelry making easier than making wax models by hand by goldsmiths.

After the 3D printing, the other steps are similar to a traditional lost wax casting method, as seen in [98]. After the 3D printing process, the 3D print is added to the wax tree-like structure, and this structure is put into a form filled with plaster. This plaster form is then put into a vacuum chamber for the plaster to get rid of the bubbles; after that, this form is heated up for the wax tree to melt, creating a mold where the metal is poured. After heating, a selected metal is melted down, poured into the mold, and moved into a vacuum chamber for metal to get into every crevice of the jewelry. After the cool down, the final

5. *Solidscape S350 | Solidscape* [online]. [visited on 2024-05-16]. Available from: `https://www.solidscape.com/3d-printers/s350/`.

mold with the cooled metal is put into a bucket of water to get rid of the plaster around the metal. Finally, the jewelry piece is removed from the metal tree and post-processed for a desired look.

5.2 Expert Evaluation

An expert from the jewelry industry was contacted to evaluate the 3D prints and the configurator itself. The jewelry expert reviewed the Neotaku configurator and 3D prints and was asked if the 3D prints could be worn for everyday use.

5.2.1 Expert Introduction

For the jewelry expert, I contacted traditional jewelry goldsmith Jiří Brosch. He was introduced to the two Lissaje and Torsion jewelry collections and the concept of the configurator tool. Additionally, numerous consultations were set up to discuss the traditional handcraft methods of jewelry making and the potential of the Neotaku configurator. After the design and implementation of the Neotaku configurator and the creation of the 3D prints, a meeting was arranged about the Neotaku website and the final 3D prints.

5.2.2 Review of Neotaku Configurator

At first, the expert reviewed the Neotaku website and the configurator itself. He tried out both Lissaje and Torsion collections on several jewelry types and examined each page. Throughout the website review, he commented that he liked the originality of the models and the website's fresh look, which was clean and minimalistic. He enjoyed the playfulness of the configurator and how a user can choose from various parameters and collection types. Additionally, he commented that it fits into the category of jewelry websites, which tend to be simpler in graphics and illustrations to let the jewelry itself shine.

5.2.3 Review of 3D Prints

After the review of the Neotaku website, it was time to showcase the three completed 3D prints from the two FDM printers and one

SLA printer. For each jewelry set, I commented on the 3D printing technique, materials used, and problems during the 3D printing.

The FDM printing techniques were discussed to be better for individuals who want to have their 3D prints from materials like plastic, but then, a user needs to consider the thickness of the material and the pattern as well. A Torsion collection is more straightforward to print on these FDM 3D printers, but the Lissaje collection would suit in bigger sizes as statement pieces of jewelry. Furthermore, the differences between the two FDM printers showcase that using better materials is essential when dealing with small and intricate details on the jewelry.

As for the SLA prints from the given 3D printer, the jewelry expert commented that resins can crumble up quickly when not properly cured. However, he added that there is a clear difference between the level of detail on FDM and SLA printers. Even though there can be problems when the jewelry piece gets malformed, it is an excellent technique for users who want to achieve a higher level of detail on smaller scales than FDM printers. However, there can be complications with the jewelry hooks, which are traditionally made from metal parts instead of resin. Nevertheless, SLA printers are a great choice when users want much more detail without using metal as a material.

Even though the metal ring with the drop-on-demand 3D printing method was still in the manufacturing process, some features of this technique were also discussed. The expert commented that the most significant benefit of this method is that it is nowadays used as a standard method in jewelry making as it helps speed up the process with drop-on-demand 3D printers. Additionally, the level of detail that can be achieved through this method is substantially higher than in the FDM or SLA printing methods.

5.3 Final Remarks

To summarize, a jewelry goldsmith, Jiří Brosch, reviewed the Neotaku website and three sets of jewelry 3D prints. The expert was thrilled with the Neotaku website, its aesthetic, simplicity of usage as well as the design of the collections. Additionally, he commented that the website is suitable for the jewelry market amongst other brands. Furthermore, the reviewed 3D prints from the two FDM printers and one SLA printer are suitable for individuals who desire quickly prototyped jewelry with materials like plastic or resin. However, there is a limit to these techniques. For the smallest details, handcrafted jewelry or usage of drop-on-demand 3D printers with lost wax casting methods is the most suitable, even if it is the priciest option.

Conclusion

The main goal of this thesis was to design and implement a configurator for 3D printed generative jewelry, which proved to be a suitable method for the customizability of jewelry products. For the design and implementation of the configurator, an analysis of existing solutions for fashion accessory product configurators was necessary. Additionally, this thesis proved that 3D printing methods can be used with product configurators to quickly prototype and create 3D prints using various 3D printing techniques.

The research conducted on fashion accessory product configurators showed that many brands started experimenting with configurators for their products, but many solutions did not offer a high level of customizability. This level of customizability can be impacted by numerous company reasons, such as the already manufactured products or the difficulty of software implementation. However, when a brand wants to use a product configurator with a high level of customizability, there must be a limit on how much the customer can change. Additionally, some discussed brands use 3D printing as a manufacturing method to create customizable and unique pieces.

An analysis of existing solutions was then used to design and implement the Neotaku website, which serves as a configurator for jewelry. The created models can be saved in a variety of 3D model formats suitable for 3D printing. This configurator contains two distinct generative collections, where a user can choose from four jewelry types. Additionally, the user can change various parameters for the given jewelry and visualize it with several materials or colors.

A qualitative user study conducted on fifteen participants showed that the Neotaku configurator has a pleasant user experience, and its users enjoyed the design and functionality of the website. However, the user study has shown that, in the future, it would be beneficial to add certain features, such as a preview of the customizable model on an image or a mockup model, an undo button in the configurator page, or new jewelry types and collections.

The final evaluation of the Neotaku website and its 3D prints was reviewed by a jewelry expert, who stated that the Neotaku website fits into the jewelry market and offers a clean, minimalistic, and playful creation process for unique jewelry. Additionally, 3D prints created on the website can be adequately used with various 3D printing techniques depending on the user's preference.

All in all, the Neotaku configurator offers a simple and pleasant solution for users who want to create customizable jewelry. The models generated by the tool can be printed using a variety of 3D printers and are suitable to wear.

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A Electronic Attachments

- Folder **_SourceCode**

  Contains the Neotaku website source code in **neotaku-website.zip**. File **README.txt** contains instructions on how to run the code.

- File **neotaku-3d-models.zip**

  Contains five .STL files of the Neotaku jewelry tested on various 3D printers.

- File **graphic-manual.zip**

  Contains a graphic manual for the Neotaku logotype and brand.

- File **user-study.zip**

  Contains a showcase of the qualitative user study with additional quantitative questionnaire and the study's data analysis.

- Link **neotaku-deployed-website**

  Redirect link for the Neotaku configurator on a deployed website.

- Link **user-interface**

  Redirect link to the Lo-Fi and Hi-Fi designs for the Neotaku user interface created in Figma.

B Additional Figures

Figure B.1: Skateboard configurator [99] created in Babylon.js [36].

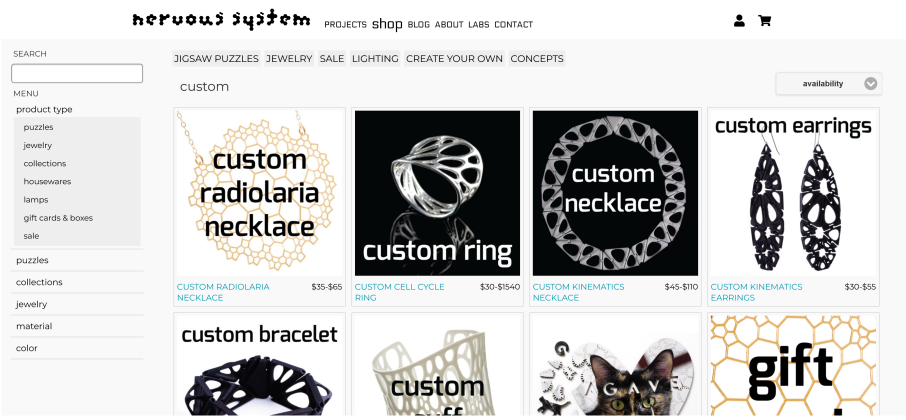

Figure B.2: Nervous System [42] custom jewelry shop page.

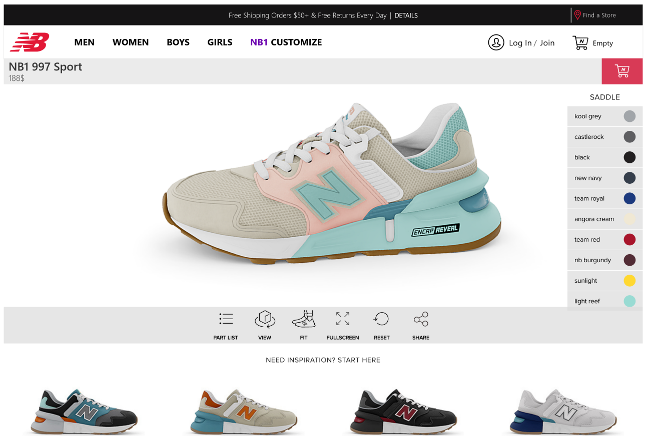

Figure B.3: Configurator for New Balance NB1 997 Sport shoes [49].

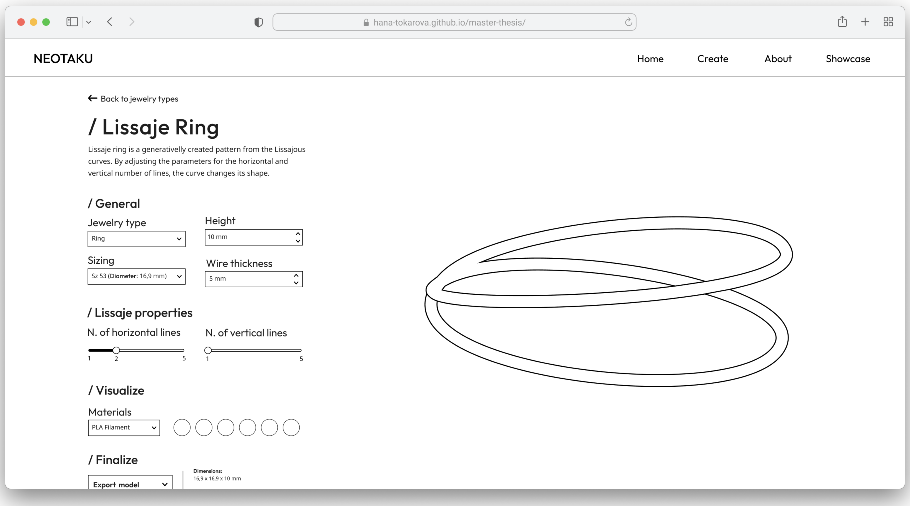

Figure B.4: Lo-Fi design of the desktop configurator page.

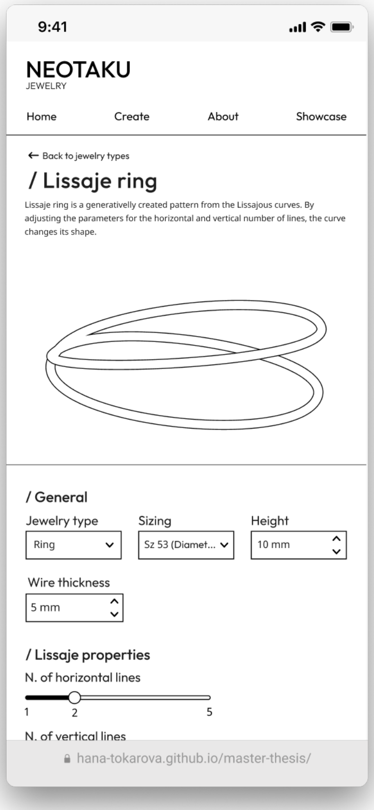

Figure B.5: Lo-Fi design of the configurator page on a mobile screen.

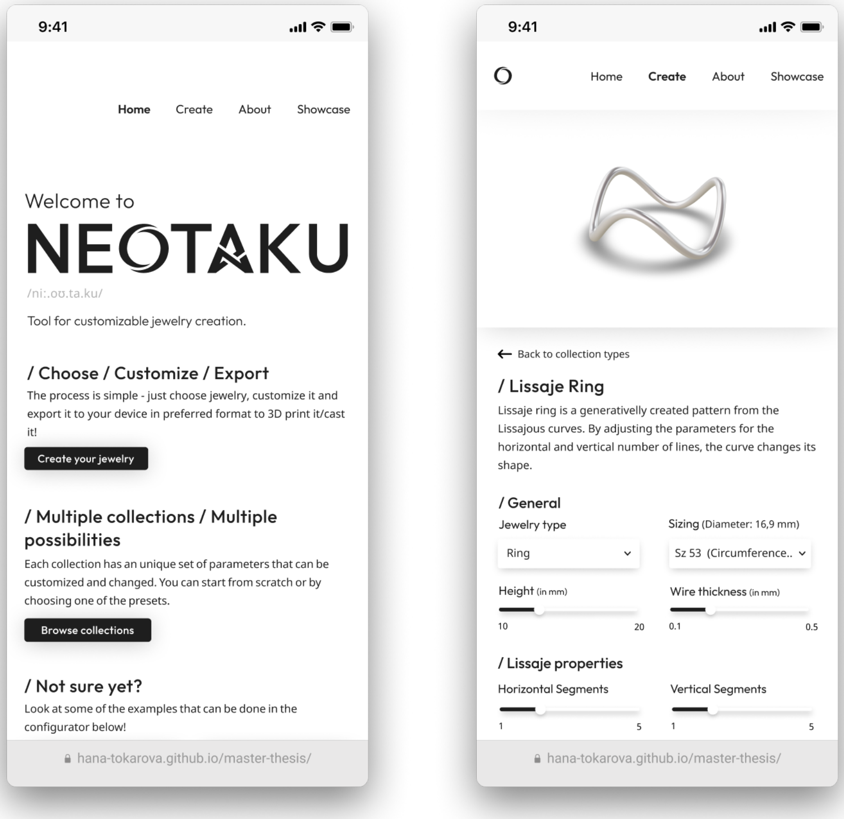

Figure B.6: Hi-Fi design of a mobile home page and configurator page.

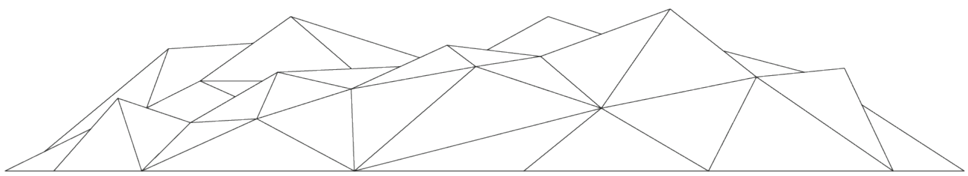

Figure B.7: Polygon Neotaku illustration.

```
src/
├── components/
│   ├── collections/
│   │   ├── Collections.tsx
│   │   ├── LissajousCollection.tsx
│   │   └── TorsionCollection.tsx
│   ├── layout/
│   │   ├── Footer.tsx
│   │   ├── MainMenu.tsx
│   │   ├── MainMenuButton.tsx
│   │   └── WebsiteLayout.tsx
│   └── utils/
│       ├── exporters/
│       │   ├── ExportGlTF.tsx
│       │   ├── ExportOBJ.tsx
│       │   ├── ExportSTL.tsx
│       │   └── Saving.tsx
│       └── mesh/
│           └── ChangeMesh.tsx
├── pages/
│   ├── AboutPage.tsx
│   ├── ConfiguratorPage.tsx
│   ├── CreatePage.tsx
│   ├── HomePage.tsx
│   ├── LookbookPage.tsx
│   └── NotFoundPage.tsx
├── subpages/
│   ├── Collection.tsx
│   ├── ColorPicker.tsx
│   ├── Contacts.tsx
│   ├── Finalize.tsx
│   ├── General.tsx
│   ├── GoBack.tsx
│   ├── Info.tsx
│   ├── Overlay.tsx
│   ├── RenderCanvas.tsx
│   └── Visualize.tsx
├── index.tsx
└── theme.ts
```

Figure B.8: `src` folder hierarchy.

```
{
  "sliderParameters": {
    "a": 1,
    "b": 3,
    "scaleB": 4.1,
    "r": 0.5
  },
  "sliderMinParameters": {
    "a": 1,
    "b": 1,
    "scaleB": 3,
    "r": 0.5
  },
  "switchParameters": {},
  "dropdownParameters": {
    "scaleA": {
      "value": 43,
      "diameter": 13.6
    }
  },
  "currentCollection": "lissaje",
  "currentJewelryType": "ring",
  "currentMaterial": {
    "name": "Metal",
    "thicknessMinimum": 0.5,
    "additionalCost": 0.3147,
    "roughness": 0.3,
    "metalness": 1
  },
  "meshColor": "ghostwhite"
}
```


Figure B.9: Example of JSON data decoded from the Base64.