# TOWARDS SEAMLESS HEATED GLOVES PRODUCED BY KNITTING.

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**ABSTRACT |** One of the long-term goals of smart clothing is to adapt the human body, just as regular clothing does. Looking at smart garments from the perspective of their entire life cycle is necessary for their sustainability. 3D technology can be a suitable choice due to its variability and adaptability. The main concept of my paper is the design of two independent gloves, where the subtle inner layer is heated, and the outer one is changeable (sky gloves, city gloves., etc.). The first crucial goal is a suitable solution for integrating the conductive paths without interrupting the yarn is crucial in the research and development of smart heated knitted gloves. The conductive path needs uniform resistance. The conventional knitting technique is not suitable for our goal because the heated segment must be divided into several areas of particular gloves. It means there are some interruptions of the conductive path.  A 90° rotation of the glove could solve this problem. The second essential part is to knit the gloves to the customer's specific requirements. It is crucial that the gloves fit perfectly and there is no unnecessary heat loss. 3D scanning obtains data about dimensions and shapes. The following converting into knitting language using a compiler could be a very useful solution. The importance of the compiler is even greater when making gloves for people with atypical dimensions anomaly or people with vascular diseases (Raynaud's syndrome, etc.).

# 1. Introduction

Smart textiles are an interdisciplinary field where products have to meet a large number of parameters to have the potential to achieve competitiveness. 3D knitting is a very effective and variable technology to produce traditional garments and clothing accessories, but it appears to be a great opportunity for the production of smart garments and smart clothing accessories as well. The advantage of 3D technology is the highly efficient production with minimal waste; garments are fully formed, eliminating the need for sewing and other manufacturing operations. The disadvantage is the difficult and time-consuming programming requiring highly skilled and experienced personnel.

This work focuses on smart heated knitted gloves designed for individuals with vascular diseases, such as Raynaud's syndrome, as well as to increase thermal comfort for sport and everyday gloves as well as work gloves and gloves for well-being. In developing knitted heated gloves, it is necessary to knit a conductive heating element with the uninterrupted yarn. The pattern of the glove is also significant. Most heated gloves are very bulky. The developed glove is intended to be used in the so-called layering approach. It means creating a very subtle inner glove with a seamlessly integrated heating element. It will be possible to wear any other glove over the inner glove, e.g., knitted or woven city gloves, ski gloves, work gloves, or rescue gloves. That´s the reason why the developed heated glove needs to be tailored perfectly. In the field of smart textiles, customization, and personalization (Arora et al., 2008) are necessary features, especially for some products in the field of rehabilitation. (Kettley, 2016) The big potential of 3D knitting is customization. According to the time demands and the final cost, the easiest way of customization is the color change option, then the knit pattern change option. Last but not least is the option of size change to meet the customer’s needs; however, that is a rather difficult process. 3D knitting has the potential to be a suitable technology for customized clothing or footwear.

# 2. Knitting Yarns

Within my research, I am involved in cooperation with a company that manufactures conductive yarns and is currently testing insulated hybrid knitting yarns, which contain light copper-silver plated 30 µm microwires that have not been commercialized yet. The tested yarns are listed in Table 1. The hybrid yarns are plied from textile polymer continuous filaments and metallic microwires. Hybrid yarns have almost the same mechanical properties as textile yarns (can be used for sewing, weaving, and knitting), can be soldered and crimped, can be produced in insulated versions, and have high resistance to wash cycles. Disadvantages are that they are not conducive all around their circumference like metalized threads (sometimes more difficult to contact, better for threads with more wires), stainless and constant threads have higher stiffness deformability and are worse for sewing.

In the picture, there is a knitting pattern where the basis is cotton, and the conductive elements are knitted with the intarsia technology, first also with cotton yarn until the conductive yarn is used after the optimal machine setting. The advantages of knitting are also the almost unlimited possibilities in combining knitting yarns to achieve the desired result. Underlay technology can be used so that the conductive yarn does not touch the skin. Conductive yarns are backed with conventional yarns when knitting hybrid conductive yarns are very similar to conventional knitting yarns, but from the point of view of comfort, backing with, e.g., merino yarn is still preferable but not necessary. This technology allows the insertion of non-textile materials such as lines or tubing. Special materials can also be inserted into the knitted fabric in the form of spacer fabric; this type of weave takes the form of a soft cushion. The great advantage of knitting lies in the possibility of combining these patterning methods within a single sample or product. Hybrid yarns have almost the same mechanical properties as textile yarns (can be used for sewing, weaving, and knitting), can be soldered and crimped, and can be produced in insulated versions with high resistance to washing cycles.

Table 1. Tested conductive threads.

| Thread | Ductility | Amount of microwires |
|---|---|---|
| 53P | 18,03 | 4 |
| 143P | 16,58 | 8 |
| 144P | 29,94 | 8 |

Figure 1. Knitted antenna samples with tested conductive and cotton threads.

## 3. Trends in the Current Garment Manufacturing

3D knitting technology brings many possibilities in design, shaping, and patterning. Knitwear development programs include visualization of garments, but it is now impossible to visualize all pattern and shape elements. The main problem in this area is the difficulty of programming and understanding the knitting technology. Designers and garment students often are not familiar with the technology, and therefore, communication with knitters is difficult. The whole product development is very time-consuming and complex. There is no communication link between the knitting software and the students' or designers' design. A solution to these problems may be the use of a converter, which is currently being developed at Carnegie Mellon University (Narayanan et al., 2018). The converter would cause the data from the 3D scanning or photogrammetry to be used to obtain accurate dimensions and anatomical shapes and then converted into a knitting language and used to create a garment or clothing accessory, in this case, a glove. Small samples ranging from very simple shapes to very complex ones were mainly knitted through these compilers (McCann et al., 2016). The use of such a compiler could lead to the creation of a perfectly fitting garment accessory and, at the same time, greater automation and simplification, referring to one of the current trends in the fashion industry, namely Fashion 4.0 (Bertola & Teunissen, 2018; Särmäkari & Vänskä, 2021), which is directly based on the principles of Industry 4.0 ( Forno et al., 2021). Above all, Industry 4.0 aims to address current challenges: meeting consumer needs sustainably and productively, which includes sustainability, adaptability, agility, and introducing the product on the market (Jin & Shin, 2021). This trend is also, very actual in 3D knitting, where seamless technology eliminates the need for stitching products. This leads to a reduction in the amount of manual labor while increasing the number of programmers and highly trained knitters required. At the same time, this would ideally increase production and, in turn, reduce waste to a minimum.

Another reason why the conversion seems to be the ideal tool is the absolute shape and dimensional customization. Conventional gloves are produced in a certain finger-to-palm ratio. If a person has long fingers or, on the other hand, very short fingers, there is a good chance that the gloves will not fit. The other option is custom glove manufacturing, where the circumference of the palm and the length of the middle finger or the length of the middle finger with the palm is commonly measured. Even this option may not be optimal. Some people also have shape anomalies, extremely oversized or missing finger links. This is a problem with conventional gloves, plus with a heated glove, these problems are multiplied. Since the heated elements do not directly touch the skin, there is the unnecessary heat loss. Therefore, 3D scanning, which can ensure a perfect fitting glove, appears to be an excellent option. In addition, for people with Raynaud's syndrome, which causes decreased blood flow to the fingers or fingertips, an individual approach is also very important in the design of the conductive heating elements so that the heating is located in the most critical areas. In certain places, the heating can be stronger and vice versa.

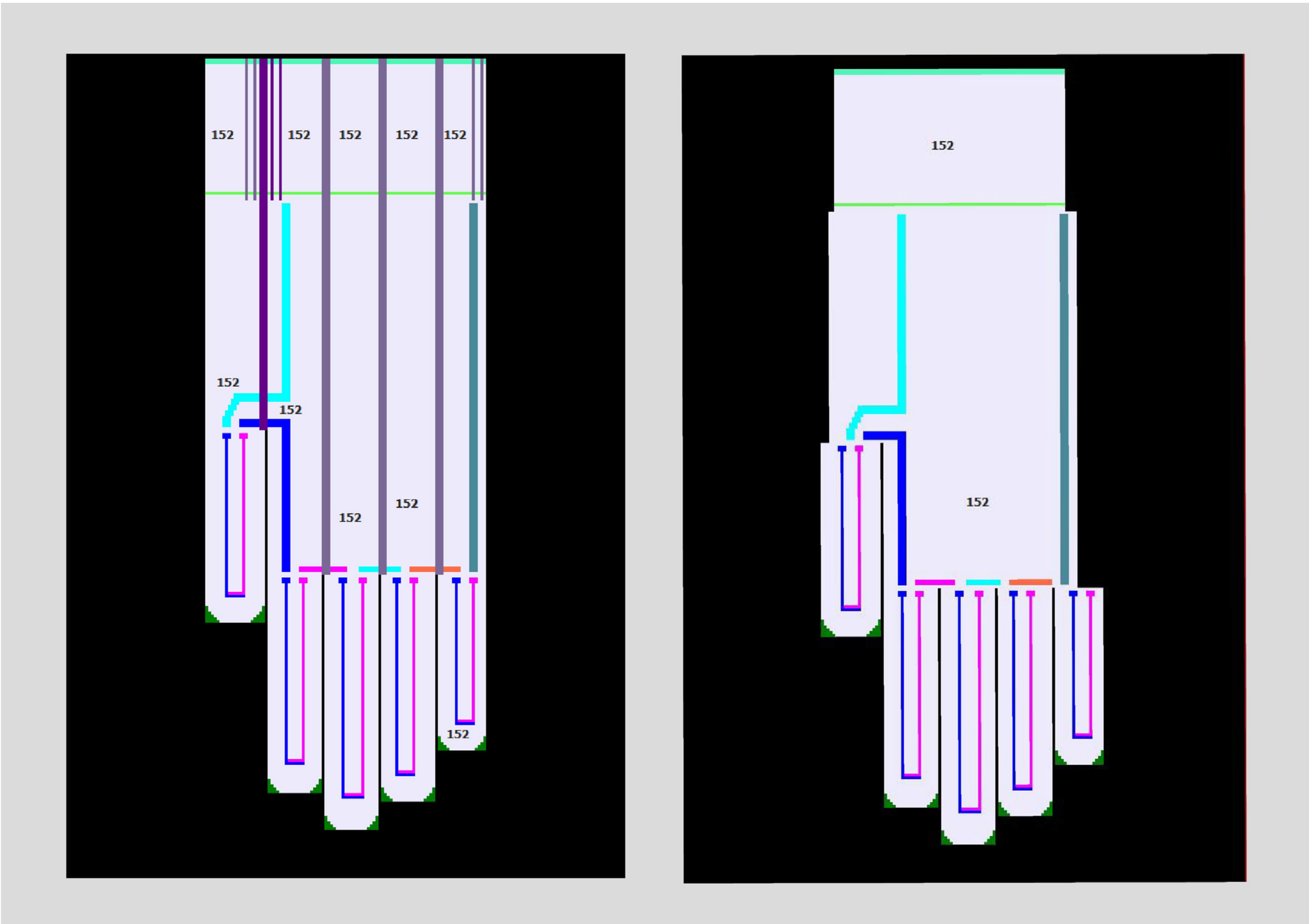


Figure 2. Conductive path design in APEX4. Each color corresponds to a different yarn carrier, i.e., the conductive path is interrupted.

# 4. Methodology

This work is based on the principles of Engineering Design Science (EDS). EDS is used in engineering to help design and build things. EDS supports engineers and designers in organizing their knowledge and understanding how the different parts of a design fit together. It also helps them solve problems and come up with new ideas. EDS is based on engineering research and experience and is used to streamline the design process. The systematic approach of EDS offers a rational and methodical path for design efforts. (Eder & Hosnedl, S., 2007, 2010a; Eder, 2010b)

Table 2. Scope of sorts of designing (Eder, W.E. and Hosnedl, S., 2008, 2010).

| **Objectives, Design Conditions** | **Design Engineering** | **Artistic – Fashion – Architectural – Industrial Design** |
|---|---|---|
| The object to be designed, or the existing (designed) object | Transformation Process and/or Technical System; primary: functioning, performing a task | Tangible Products; primary: appearance, functionality |
| Representation and analysis of the object as designed, and its captured design intent | Preparing for TS(s) manufacture, assembly, distribution, etc. AI, CAD/CAM/CIM | Rendering for presentation and display, product range decisions |
| Design process (for the object), methodology, generating the design intent | Theories of designing, Engineering Design Science, formal design methodologies | Intuitive, collaborative, interactive designing |
| Properties of the object as output of designing | Mediating and Elemental Design properties, to establish observable properties | Observable properties to achieve customer satisfaction |
| Design phenomenology | Empirical, experimental and implementation studies | Protocol studies |
| Responsibilities | Professional, ethics, reliability, safety, public legal liability, enterprise, stakeholders | Organisation, stakeholders (Architecture adds organizational and contract responsibility Artistic – Fashion – Architectural – Industrial Design) |
| Location | Design/Drawing Office | Studio |

# 5. The Development of the Heated Glove

The main objective is a personalized product for a specific person and, above all, the development of the glove with an uninterrupted conductive path to avoid interruption of the electrical circuit. Another goal is the integration of smart technologies to sense human and ambient temperature through embroidery or knitting. The individual adaptation of the glove to the customer's specific needs is important. The product under development may find many potential users to reach a various target group: a very specific group of people with Raynaud's syndrome, medical professionals, or general users who want to increase their thermal comfort at very low temperatures.


Figure 3. Samples of gloves with interrupted conductive paths.

In the first phase of the development, yarns were selected, followed by density testing. When the density was appropriate, we could proceed to the next step of programming the glove: this involved entering dimensions, programming structures, and color patterning, in this case, conductive yarn patterning. The first samples of the gloves were knitted conventionally. At first, the fingers were knitted from the fingertips. Then, the palm was knitted, followed by the thumb, also from the fingertips, and then the glove was knitted up to the hem in the form of a tubular piece. The conductive path was worked in intarsia. Intarsia is a knitting technique that is used for knitting with multiple colors or multiple yarns. In this first method, the conductive path was divided into several areas, namely fingertips, the area where the fingertips meet the palm, and the back of the hand, which was undesirable. For this reason, heating elements were simplified and left only in the fingers´ area. Moreover, when considering that when it comes to heating the hand, the most crucial is the heating of the fingers, where the cold occurs. Thus, the simplification of the glove warming was not a problem. After several further attempts, this method of knitting could not be fine-tuned to avoid interrupting the yarn.  It was necessary to find another way to knit. An unusual way was then devised where the glove was turned 90° and knitted in width. The first sample of this knitting method was knitted as a flat sample only. This sample has shown that such a knitting technique would be suitable for knitting the heated glove and should not break the yarn.

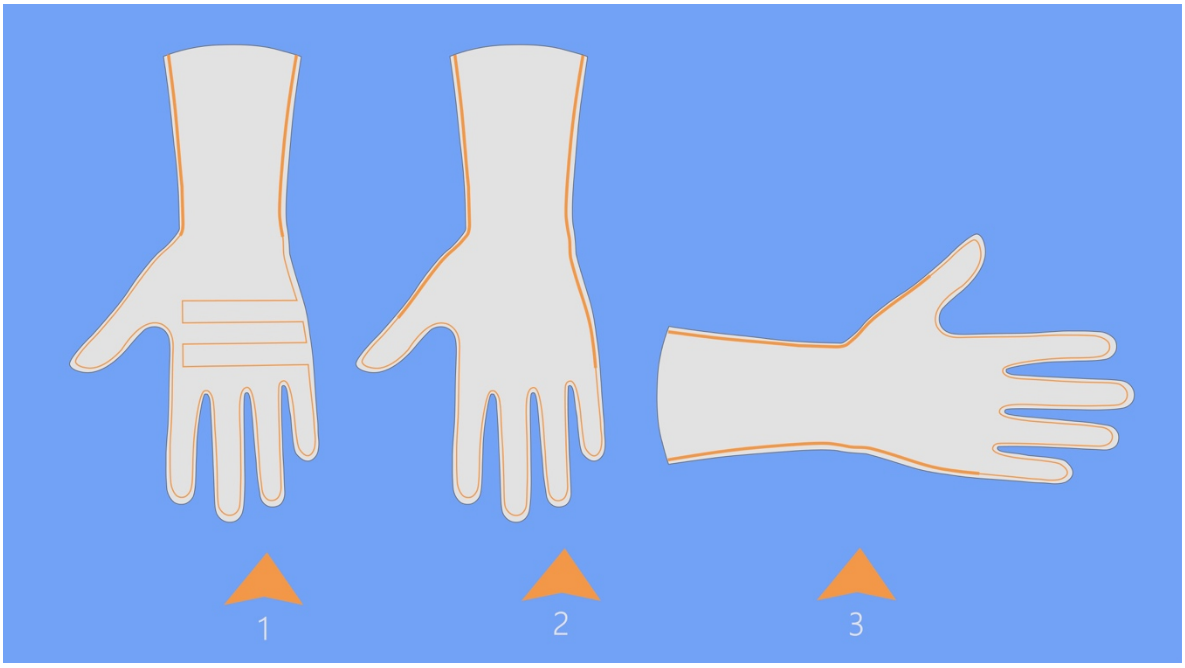


Figure 4. Development of the design of the heated inner glove. (The orange line indicates the heated conductive path. The direction of the arrow shows the direction of knitting.)

The advantage of intarsia is that we can knit thin multi-colored knits, on the other hand, each part is knitted with a different conductor. The heated segment must be designed following these rules so that the conductive path is not interrupted, which would result in resistance breaking, and therefore, unwanted uneven heating or interruptions would have to be encapsulated or ultrasonically welded, which is not desirable.

## 6. Sustainability

Each conventional glove is designed for a specific activity, and if we wanted to heat each type of glove, a large number of rechargeable batteries would be required as each product usually requires a different battery, which does not seem sustainable. The research and development of the heated glove focuses on the entire life cycle of the product, from raw material sourcing to disposal and recycling. The most important trend not only in this area is quality. The quality of the raw materials, but also the quality of the assisting inputs, the quality of the technology, the quality of the production or the environment, and the quality of disposal and recycling are important. We, therefore, work with high-quality materials and design all components to be replaceable or repairable. The concept of heated one-layer gloves allows us to reduce the number of batteries needed. So, the user only needs 1 or 2 pairs of batteries, and all their gloves can be heated.

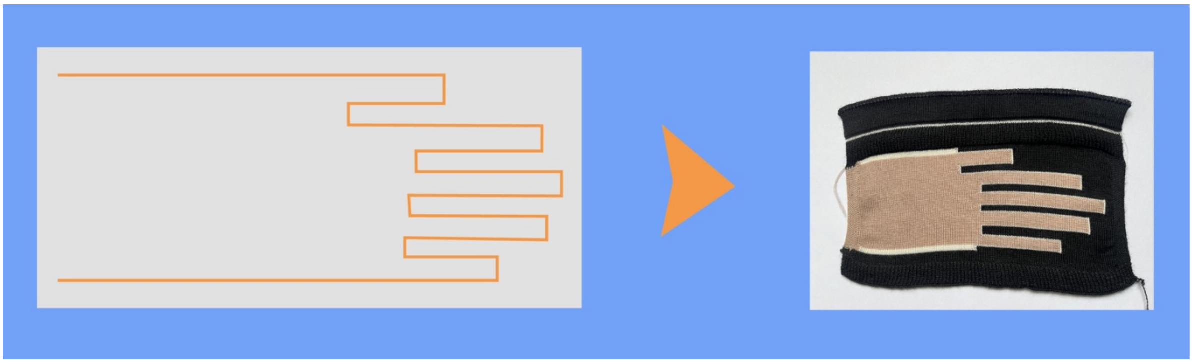

Figure 5. Flat pattern design with conductive path and knitted flat pattern. In this pattern, we used a 90° rotation of the glove.

## 7. Conclusion

This paper has demonstrated an approach that we want to further enhance the development of heated knitted gloves. The cornerstone is to divide the glove into two separate layers, with the inner layer being heated. In the first phase, one of the optional possibilities is to obtain the dimensions of the hand using a 3D scan, and then the data could be processed by a converter (Narayanan et al., 2018) and used in APEX4 (SHIMA SEIKI, 2023). Once the density tests have been knitted, accurate hand-dimension data can be used. The glove will be knitted unconventionally, i.e., rotated 90° which will allow the use of the intarsia pattern throughout the glove without interrupting the conductive path, as in the flat sample in Figure 5, where the conductive yarn is demonstrated with a white merino yarn.

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