

## Geometric developments in functional clothing

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### ABSTRACT – REZUMAT

#### Geometric developments in functional clothing

*This study presents a geometric development of functional clothing (for pregnant women). In the beginning, we discuss the main changes women's bodies undergo during pregnancy and the requirements of an adequate wardrobe. Using specific design tools (Gemini CAD – a Lectra Company), we develop a geometric network for designing made-to-measure maternity clothes (case study – blouse). From this network, three specific blocks have been developed in accordance with the body changes. The estimated increments of the second and third pregnancy trimesters have been expressed as correspondent angles and used to design the adequate shape of the blouse patterns (front and back). We have also evaluated the blouse patterns when dressed on the corresponding avatars for each trimester via 3D simulations.*

**Keywords:** functional clothing, geometric development, network, blocks

#### Dezvoltări geometrice în îmbrăcămintea funcțională

*Această lucrare prezintă o dezvoltare geometrică a îmbrăcămintei funcționale (pentru femeile însărcinate). În partea introductivă sunt discutate aspecte teoretice referitoare la principalele schimbări pe care le suferă corpul femeilor în timpul perioadei de sarcină și cerințele unei garderobe adecvate pentru această perioadă. În lucrare, se elaborează o rețea geometrică necesară proiectării personalizate a produselor vestimentare pentru femei însărcinate, în funcție de trimestrul de sarcină (studiu de caz – bluză), utilizând instrumente avansate de proiectare CAD (Gemini CAD – o companie Lectra). Pe baza acestei rețele, în funcție de modificările corporale specifice fiecărui trimestru de sarcină, au fost dezvoltate trei blocuri, câte unul pentru fiecare trimestru. Creșterile corporale aferente trimestrului doi și trei de sarcină au fost exprimate sub forma unor unghiuri corespunzătoare și au fost utilizate pentru a proiecta forma adecvată a elementelor principale de produs ale blocurilor (față și spate – bluză). Validarea formei elementelor de produs ale blocurilor personalizate s-a realizat prin simulare 3D; prototipurile virtuale ale blocurilor au fost îmbrăcate și analizate pe avatarurile corespunzătoare pentru fiecare trimestru de sarcină.*

**Cuvinte-cheie:** îmbrăcămintă funcțională, dezvoltare geometrică, rețea personalizată, blocuri

### INTRODUCTION

Clothes are designed and manufactured to fulfil the customers' needs: comfort, protection, aesthetics and others according to the product's destination and utilisation. Functional clothes represent a category designed to meet special user needs for particular situations: protection (from high or low temperatures, rain, snow, wind, UV light, fire, skin contact with dangerous substances, radioactivity, etc.), health functions (ensure good blood for better blood circulation, monitoring heart rate, blood oxygenation or body temperature), athletic function (improves performance, lowers fatigue), aesthetic function (shaping the body for a better aspect), complex functions (multifunctional performance, protection, support, comfort), special needs support (for infants, people with disabilities, elderly, pregnant women) [1].

The shape and structure of functional clothes (the number of pieces/models, the geometry of the outline contour of each piece) are influenced by their destination. The materials and manufacturing technology of these items contribute to their performance and

functionality. In the design process of this type of clothes, it is necessary to consider ergonomic requirements such as the degrees of freedom, momenta of forces in human joints, forces, posture, proportions, conformation, etc.) [2–5].

Clothes for pregnant women have to be designed according to the specific needs and requirements of this period, especially by taking into account the physical modifications from one pregnancy trimester to another. Nowadays, the market for this type of product offers items with the following details to ensure wearing comfort: large volume (pleats, folds and creases), adjustable straps and flexible and variable closure solutions (buttons, staples, elasticated bands) manufactured for typical bodies. The existing range of this type of clothing is not adapted to the diversity of women's body shapes; some of the items produced do not sell because they do not fit any customer (these items become waste). This situation can be changed through a win-win solution for manufacturers and customers: designing and manufacturing ready-to-wear or made-to-measure clothes. The

CAD producers have developed specific modules for the geometric development of the shapes of the garment pieces (made-to-measure module) where the designer has the possibility to decide on the shape of the garment pieces by taking into account the peculiarities of the body shape and model details. In this paper, the authors propose the development of a personalised geometric network for a blouse that can be adapted to the specific changes in the body for each trimester of pregnancy [6]. This network is used to develop three blocks for each trimester of pregnancy. The outlines of the main elements of the blouse (front, back and sleeve) are drawn in the designed network and automatically linked to the value of the initial data, and the body changes from one trimester of pregnancy to the next.

## GENERAL INFORMATION

### General information about body changes

Pregnancy is an important event in every woman's life, with physical, hormonal and emotional changes. Significant lifestyle changes must be made to ensure the child's normal and healthy development. The mother's state of health, age and social, professional, and physical activities influence the evolution of her body shape during pregnancy. During this period, the body silhouette, posture, size and weight change differently depending on the trimester of pregnancy: in the first trimester (1–12 weeks) the body does not undergo any physical changes (this period is a transition to the new stage: mood swings, strong sense of smell, nausea and vomiting, etc.), in the second trimester (13–28 weeks) important changes in shape and weight take place (the abdomen grows because the fetus/baby is growing), while in the third trimester (29–40 weeks) the body weight, posture and shape are completely different (the mother's body has to strike a new balance between its weight and the baby) (figure 1) [7].

Pregnancy clothes must be comfortable and beautiful but perfectly adapted to the pregnancy trimester. The future mother must be able to work and be involved in different social activities, so she has to find proper and diversified clothes. While she can wear clothes from her already existing wardrobe during the first trimester, in the 2<sup>nd</sup> and 3<sup>rd</sup> trimesters she must wear suitably sized products. The first noticeable physical changes occur around the fourth month (second

trimester). These changes require special care in developing maternity clothing in terms of comfort, fit and size.

Medical studies have shown that women gain about 10–16.5 kg during pregnancy depending on their age and BMI [9].

Most women notice an increase of 20 to 26 centimetres around the waist. The expansion of the abdomen varies depending on the position of the foetus. Some pregnant women carry their baby low, and others high. Sometimes, the abdomen appears to be pushed forward or hidden in the body. The breasts also increase in size, with a peak of 5–8 cm in terms of average circumference. The waist circumference may increase by up to 37 cm, and the hip and high hip circumference (10 cm below the waist) may increase by up to 36 cm [10]. The body depth increases differently at the main levels: the bust level (chest depth) increases by around 1%, the abdominal level increases by 4%, the hip level increases by 1%, and the upper thigh level increases by 7% (concerning the values before pregnancy) [11].

During pregnancy, the spine is temporarily curved to keep the body in equilibrium (balanced). This changes the posture, with the body tilted backwards. The change in posture, the centre of gravity, and weight cause discomfort: lower back pain, pelvic girdle pain, fatigue and general malaise [12, 13].

Besides physical transformations, pregnancy brings noticeable psychological changes: emotional fluctuations between a happy/normal state and a fearful/agitated one. Society, friends and family must provide emotional support to pregnant women because their emotional state has a significant influence on the development process of the fetus.

### Clothes for the pregnancy period

Clothing plays an essential role in reaching and maintaining self-confidence. Clothes must be comfortable, beautiful, of good quality, varied (model and category) and affordable. Due to physical changes, clothes that fit in the second trimester will be inappropriate in the 9th month (in the first trimester, women can wear usual clothes as the size and shape of the body do not change). On the other hand, the women's preferences may vary: some prefer styles and product categories that emphasise the shape of the belly (because they are proud of their baby bump), while others prefer oversized clothes (for more comfort). During this period, women are very sensitive to contact with clothing surfaces; for this reason, they look for apparel made from materials with natural fibres.

The maternity clothing market represents a small part of the general one. This type of clothes (blouses, sundresses, overalls, cardigans, dresses, T-shirts) can mainly be bought in specialised shops and department stores, where the range is not as varied and profitable as in other shops (figure 2).

For ergonomic and functional reasons, clothing for pregnancy is designed with support on the shoulders.

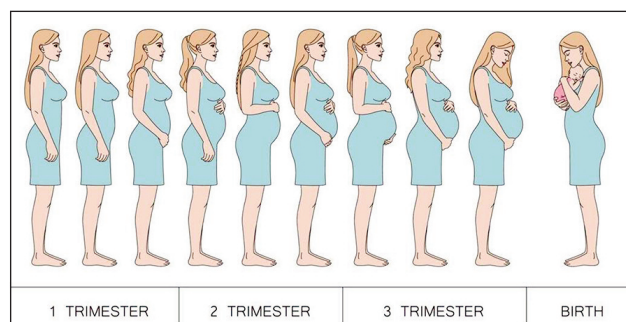


Fig. 1. Stages of pregnancy [8]



Fig. 2. Examples of clothes for pregnant women (2<sup>nd</sup> and 3<sup>rd</sup> trimester) [12]

The styles have accessible fastening solutions (buttons, staples) with or without straps (with adjustable length), usually with a cross-section above the waist (yoke) and pleats/folds or creases on the component(s) below the yoke (figure 2).

The nine months of pregnancy are an important part of a woman's life. During this time, she wants to wear different garments that are fashionable, ergonomic, comfortable and fit her body shape perfectly. The size of the garments worn during this period must be the same as before the pregnancy because the garments must be well-balanced on the body (to ensure psychological comfort).

### GEOMETRICAL DEVELOPMENTS IN FUNCTIONAL CLOTHING

The fit of functional clothing is considered successful when the needs of the wearer are harmonised with the required functionality of the garment. There are two essential aspects—comfort and appearance. Comfort is perceived by the customer when wearing the garment, and appearance refers to the look, style and fashion. The fit is determined by the interaction of various factors: the shape and biomechanics of the human body, the textile materials (the interaction with the body shape and the ones between them) and the details of the model [13–15].

Lectra, Gemini – a Lectra company –, Assyst, Optitex and Clo3D are often used to develop the shape of the model patterns and to obtain a virtual 3D prototype. In a 3D environment, the designer checks (validates) the methodology used to obtain the shapes of the pieces of the pattern and analyses the position and appearance of the garment model dressed on a virtual avatar (this consists of checking the balance of the model and its fitting degree). In other words, even if these products are considered functional, they must also fit into fashion trends and be manufactured on demand (as personalised or made-to-measure items) or in minimal series (according to the market requests). Suppose the manufacturer has the possibility to communicate with the customer, to determine her preferences or needs, and to evaluate/measure some key body dimensions (using non-invasive measurement technology-scanning apps). In that case,

they can use all the data to develop the shape of the desired items in a particular way (the designers will have the possibility to obtain the 3D model prototype and check its appearance when dressed in the client's avatar). Suppose the manufacturer cannot obtain specific data on the customer's preferences and body dimensions. In that case, they developed the new model using standardised information on body measurements [16] and the results of previous marketing studies applied on the market (among the customers) to identify which category and number of products should be manufactured.

Based on all the aspects of the specificities of pregnancy already discussed and analysed in the previous sections of this article, a solution for the geometric development of made-to-measure maternity clothing (case study – blouse) using specific tools of the Pattern Design module (Gemini CAD-a Lectra Company) can be found by going through the following steps:

- a) Deciding which key data is needed to design a customised network;
- b) Determining the structure of the mathematical relations needed to develop the personalised network (design methodology);
- c) Designing the 3 basic blocks about the particularities of each pregnancy trimester;
- d) Extracting the shape of the main elements. Creating the virtual 3D prototype and analysing it;
- e) Altering the size and shape of the main elements (if necessary). Validating the design solution.

The Pattern Design module (from Gemini CAD-a Lectra Company) has specific functions/tools and instruments that enable the designer to interactively obtain the shape of the main elements, as their size and shape are determined by selected initial data via various mathematical relations [17, 18].

- a) Deciding which key data is needed to design a customised network;

The necessary data for designing the blouse network can be classified into the following categories: values of the body dimensions, values of product dimensions, values of allowances (constructive allowance for the bust level); and lengths of different contour lines, which have been measured on the main pieces (front and back) (figure 3)

- b) Determining the structure of the mathematical relations needed to develop the personalised network (design methodology);
- c) Designing the 3 basic blocks in relation to the particularities of each pregnancy trimester;
- d) Extracting the shape of the main elements (front, back and sleeve).

The personalised network is designed using various mathematical relationships (case study blouse) and specific tools from Gemini CAD's Made-to-Measure module (figures 4 and 5).

The shape of the blouse elements (first block) is drawn in this network.

The necessary steps in obtaining the shape of the main elements consist of: connecting the points in the geometric layer by drawing straight lines (Draw tool);



alias	index	alias	Dimensions	Body height	Bust perimet	Bust allowan	Sleeve length
				174	92	6	59

No	Short	Name
1	Ic	Body height
2	Pb	Bust perimeter
3	Ab	Bust allowance
4	Lm	Sleeve length
5	Apo	Scapula dart
9	Inuf	Front shoulder h
10	Inus	Back shoulder h
11	Pcm	Sleeve length
8	Pm	Armhole length

Fig. 3. Key data for designing the blouse network

Description of the selected geometrical operation

Create a new point **P14** from point **P12** at  $-(0.18 \cdot Pb + 0.5 + 0.2 \cdot Ab)$  cm horizontally and **0** cm vertically

Fig. 4. Back width

Description of the selected geometrical operation

Create a new point **P18** from point **P16** at **0** cm horizontally and  $[P1, P2] + 3.5$  cm vertically

Fig. 5. Front height

converting the straight lines into curves and modelling their shape (neckline, armhole and hem) by using the Shape tool; moving the pieces from the geometric layer (Piece Tool) (figure 6). When the

pieces are moved, the connection with the geometric layer is not destroyed (if a value of the initial data is changed, the shapes of all the pieces are automatically redrawn).

Fig. 6. The blouse patterns (front, back and sleeve – for 1/2 of the product). First block

The next two blocks are designed by using the previous one as a starting point. Based on the previous information about how the shape of the body varies, the following steps are going to be necessary:

- the width of the front piece will have to be changed. For the second block, one will have to use 40% of the body increment (waistline). For the third block, 60% of the body increment will have to be used;
- the front pattern will have to be divided into 2 pieces (by drawing a vertical line through the bust point). The lateral part is then going to be slanted by a specific angle (the value is in sexagesimal degrees, taking values between 0° and 360°). The value of the angle is determined by considering the increment at the waist level and the length of the vertical line used to divide the front pattern;
- the back will also have to be divided by a vertical line drawn from the vertex of the scapula dart. The lateral part is also going to be slanted by an angle (the value is in sexagesimal degrees). Its value is determined by considering the increment at the bust level (partial) and the vertical line length used to divide the front pattern.

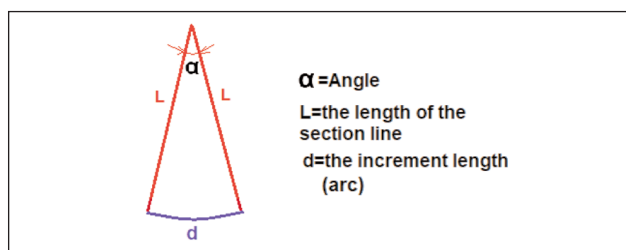


Fig. 7. Details for determining the value of the  $\alpha$  angle

The general formula used to determine the value of the angle is (the terms are explained in figure 7):

$$\alpha = \frac{180 \cdot d}{\pi \cdot L} \quad (1)$$

Based on the information already described, the corresponding angle of the increment on the waist (front

piece) and bust (back piece) has been determined for the 2<sup>nd</sup> and 3<sup>rd</sup> trimesters of pregnancy. For the front element, only the increment on the waist level was necessary, because in the 2<sup>nd</sup> and 3<sup>rd</sup> trimesters, the body undergoes major changes at the waist level, more significant than at the bust (the front piece has to cover the new shape of the body).



Fig. 9. The virtual prototype

The new pieces have been imported into CLO [19] to obtain the 3D virtual prototype that is going to be tested on the corresponding avatar (2<sup>nd</sup> trimester).

By analysing the appearance of the virtual prototype; we can reach the following conclusions:

- the widths of the elements (front, back and sleeve) are well-dimensioned;
- the product is well-balanced;
- the position of the front hemline must be changed (lower).

In the design scenario for the front element, the position of the hemline has to be changed. To do this, one has to evaluate the height of the front middle point and the one of the back middle point. The difference between these heights is then used to change the level of the front hemline.

The shapes of the main elements (front, back and sleeve) for the third trimester are obtained by applying the same procedure.

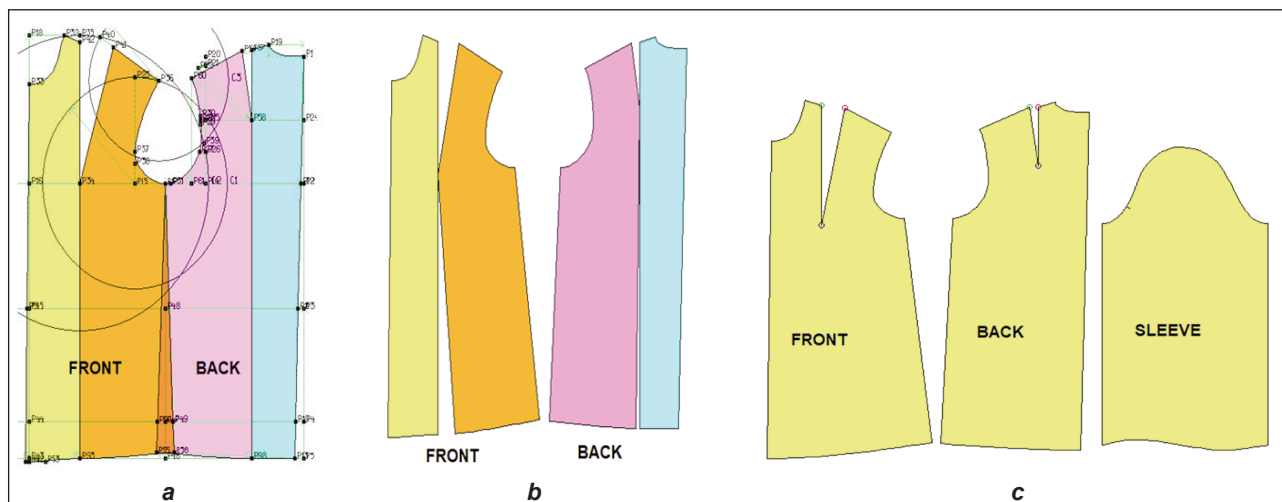


Fig. 8. The block patterns for the 2<sup>nd</sup> trimester: a – draw the section lines; b – rotate lateral pieces; c – final patterns (1/2 product)

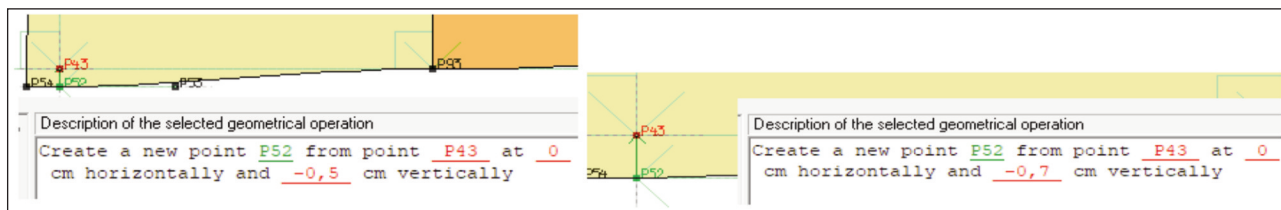


Fig. 10. Alteration of the front hemline position

## CONCLUSIONS

The digital development of this type of product involves the following steps: designing the 2D shape of the components, creating the virtual 3D prototype (selection of materials) and evaluating the appearance of the corresponding avatar. A geometric development of the size and shape of the garment pieces, based on the peculiarities of the body changes, may fulfil the customer's needs.

The geometric development of the blouse patterns concerning a network involves describing the dependence of the shape of the garment pieces on the changes of the body (increments) and model details by using mathematical relations. The proposed design solution allows:

- interactive changes in the network size, determined by alterations of the initial data (values or structure) or the structure of the mathematical relations. The shapes of the blouse components (front, back and sleeve) are automatically redrawn because they are determined by the geometric network;
- the possibility of considering the body changes (increments) during pregnancy in adapting the shape of the front and back patterns (the 2<sup>nd</sup> and 3<sup>rd</sup> trimesters). These have been used to calculate the values of the corresponding angles “ $\alpha$ ” (for the

front and back patterns), for the 2<sup>nd</sup> and 3<sup>rd</sup> trimesters (40% for the 2<sup>nd</sup> trimester and 60% for the 3<sup>rd</sup> trimester);

- if, during the simulation phase for the front element, some tension forces occur within its surface, the mathematical relationship used to dimension its width will have to be readjusted so that it takes into account the increment in breast circumference from the 2<sup>nd</sup> to the 3<sup>rd</sup> trimester, with the same coefficient used for the bust circumference;
- the network can be personalised for different body postures and conformations or other clothes with support on shoulders;
- the shape of the main elements can be easily changed/modelled according to the customer's demands (fashion on demand).

As for further developments, the proposed solution can be used to develop geometric networks for garments with support at the waist (trousers) or models with different cut lines (e.g. raglan cut) (e.g. raglan cut).

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## REFERENCES

- [1] Deepti, G., *Functional clothing – Definition and classification*, In: Indian Journal of Fibre & Textile Research, 2011, 36, 321–326, Online ISSN: 0975-1025, Print ISSN: 0971-0426
- [2] Broadhead, R., Craeye, L., Callewaert, C., *The Future of Functional Clothing for an Improved Skin and Textile Microbiome Relationship*, In: Microorganisms, 2021, 9, 6, 1192, <https://doi.org/10.3390/microorganisms9061192>
- [3] Avadanei, M., Olaru, S., Ionescu, I., Ursache, M., Ciobanu, L., Alexa, L., Luca, A., Olmos, M., Aslanidis, T., Belakova, D., Silva, C., *ICT new tools for a sustainable textile and clothing industry*, In: Industria Textila, 2020, 71, 5, 504–512, <http://doi.org/10.35530/IT.071.05.1811>
- [4] Olaru, S., Mocenco, A., Teodorescu, M., Niculescu, C., Salistean, A., *Shape categories for the Romanian female population and specific clothing recommendations*, Industria Textila, 2011, 62, 3, 155–160
- [5] Chen, J.-Z., Guo, Z.-Y., Li, T., Du, L., Zou, F.-Y., *An undamaged pattern generation method from 3D scanned garment sample based on finite element approach*, In: Industria Textila, 2023, 74, 1, 35–41, <http://doi.org/10.35530/IT.074.01.202185>
- [6] MyungHee, S., *A Pattern Adaptation for Body Changes during Pregnancy: A Single Case Study*, Master Thesis, University of Minnesota, November 2009
- [7] Rn, N.G., *Pregnancy trimesters: Everything you need to know. Medical and health information*, 2018, Available at: <https://www.medicalnewstoday.com/articles/323742> [Accessed on November 20, 2022]
- [8] *Stages of pregnancy*, Available at: <https://www.freepik.com> [Accessed on November 20, 2022]
- [9] *Weight gain in pregnancy*. (n.d.). Pregnancy, Birth and Baby, Available at: <https://www.pregnancybirthbaby.org.au/weight-gain-in-pregnancy> [Accessed on November 17, 2022]

- [10] Cieśla, K., Frydrych, I., Krzywinski, S., Kyosev, Y., *Development workflow for virtual design of clothing for pregnant women*, In: Communications in Development and Assembling of Textile Products, 2020, 1, 2, 148–159, <https://doi.org/10.25367/cdatp.2020.1>
- [11] Faust, M.E., *Designing for Pregnant Women*, In: Proc. of the 4th International Conference on 3D Body Scanning Technologies, Long Beach CA, USA, 19–20 November 2013
- [12] *Maternity clothes*, Available at: <https://www.freepik.com/free-photos-vectors/maternity-clothes/> [Accessed on November 20, 2022]
- [13] Boorady, L.M., *Functional clothing – Principles of fit*, In: Indian Journal of Fibre & Textile Research, 2011, 36, 344–347, Online ISSN: 0975-1025, Print ISSN: 0971-0426
- [14] Olaru, S., Filipescu, E., Niculescu, C., *Morphological indicators for characterization of women thorax and basin shape, for garment design in customised*, Industria Textila, 2011, 62, 6, 289–295
- [15] Rosca, M., Vatra, A.-D., Avadanei, M., *The digital transformation of garment product development*, In: Industria Textila, 2023, 74, 1, 98–106, <http://doi.org/10.35530/IT.074.01.2022148>
- [16] ASTM D7197-13, *Standard table of body measurements for misses maternity sizes two to twenty-two (2-22)*, ASTM International, <https://doi.org/10.1520/D7197-13>
- [17] Filipescu, E., Avădanei, M., *Structura și proiectarea confecțiilor textile. Îndrumar laborator*, Ed. Performantica, Iași, 2007, ISBN 978-973-730-412-4
- [18] Gemini – a Lectra company, Available at: <https://www.geminiCAD.com> [Accessed on November, 2022]
- [19] Clo3D, Available at: <https://www.clo3D.com> [Accessed on November, 2022]

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