SIMULATION OF THE SEGMENT FILLING INSERTION FABRICS AT THE YARN LEVEL

FANG JIAHUI[1,2*], KYOSEV YORDAN KONSTADINOV[2], LI YULING[1] AND MA YANXUE[1]

[1] College of Textiles, Donghua University, Shanghai, 201620, China
[2] Technische Universität Dresden, Dresden, 01069, Germany

ABSTRACT

Fabrics with segment filling insertion are finding application in several traditional luxurious textiles, clothing, and in the latest time as well for smart textiles. Segment filling allows the integration of conductive yarns for contacting areas, keeping the textile character of the structures. This work presents a method for 3D modeling woven structures with segment filling at the yarn level. The pattern image is analyzed by an image processing tool, written in Python, and used to create the initial weaving information. After that, the different regions are filled with suitable preselected weave types, such as plain, twill, or others. Finally, this data is used to compute the 3D coordinates of the weft and warp yarns, and saved in a suitable format. The 3D visualization is done by the TexMind Viewer, which allows its advanced version export in various formats for FEM, CFD, and other computations.

KEYWORDS

Segment filling insertion fabrics; Yarn level; Product development; 3D simulation.

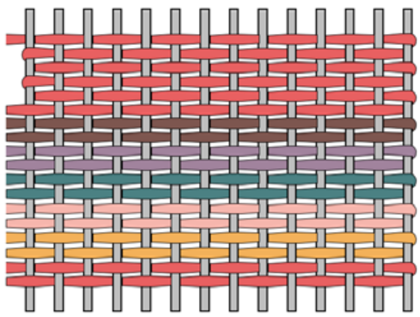
* **Corresponding author:** Fang J., e-mail: *fangjiahuizfh@163.com*

INTRODUCTION

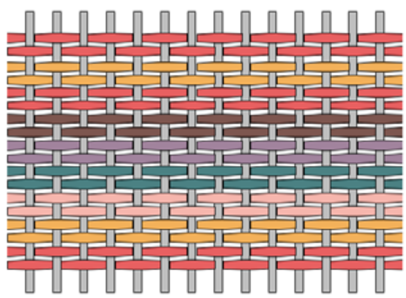
According to the filling insertion method [1], weaving looms can be divided into shuttle looms and shuttleless looms, the weaving looms were all based on the normal filling method until 2019. As shown in Figure 1, every weft is filled from one side to the other with one single yarn in fabrics with a plain weave. Meanwhile, many researchers have taken numerous approaches in yarn-level woven fabric modeling [2]-[4] based on the normal filling method [5]-[7].

With the improvement of automatic techniques, segment filling insertion fabrics (see Figure 2) can be weaved by a modified dobby loom in 2019 [8]. The segment filling insertion fabrics are pretty complex, different from the normal woven fabrics, where the fabrics are composed of yarn-level patterns based on repeated sections[9-10]. As each row is composed of several yarns of different colors, which can be turned back at any position.

The method for 3D simulation of woven structures with segment filling at the yarn level is systematically proposed in this work. Characterization of yarns in the segment filling insertion fabric as is shown in Fig. 2, For the simulation of segmental filling insertion fabrics, the challenge is that the trajectory of the weft yarn is flexible, i.e., it can start and end at any position, in addition, it is continuous between different rows, the connection between the end of one row and the start of the next row is also much more complicated compared with normal woven fabrics.



(a) Fabrics woven by shuttle loom



(b) Fabrics woven by shuttleless loom

Figure 1. Normal filling insertion fabrics.

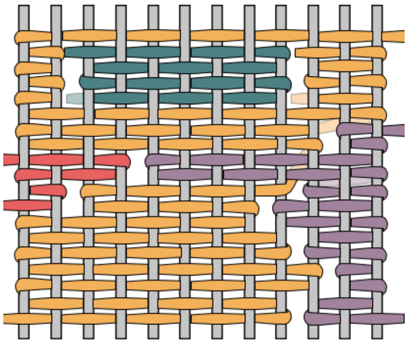
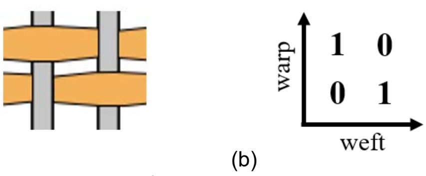


Figure 2. Segment filling insertion fabrics.

EXPERIMENTAL

The simulation parameters are obtained through imaging analysis, area division, weave filling, and orientation property marks of key positions along the yarn trajectory. A topology-based model, similar to those reported for braided structures [11] or in the general case for any textile architecture [12] was developed as a parametric mathematical model and then implemented in a Python program.

In the past years, a matrix of '0' and '1' is generally applied to describe the structure of a fabric [13]. In simulation analysis as well as 3D modeling of fabrics [14-15], this matrix describes the position relationship of warp and weft yarns, that is, the Z coordinate in the 3D coordinate system. Taking plain weave fabric as an example, as shown in Figure 3, its basic organizational structure matrix is shown in Figure 3(b). For other parameters [16-17], such as yarn geometry (e.g. yarn length, fineness, yarn spacing, etc.), yarn mechanics (e.g. initial modulus, strength, elongation, etc.), yarn color parameters, etc. The common feature of the above simulation as well as the modeling of woven fabrics is that the normal weft yarns are continuous in the row as well as disconnected at both ends. For the calculation of the key coordinates of the yarn trajectory, it is not necessary to consider the relationship between wefts. More realistic methods for the representation of the yarns at the fiber level can be implemented in the future, as reported by Liu et al. [18], but in the current work, the specific areas of the weft yarn transition have to be considered and modeled more detailed.



(a) (b)

(a) Schematic diagram of plain weave
(b) Matrix code for organization chart

Figure 3. Plain weave and its corresponding matrix.

Methods

In this study, the initial pattern (noted as matrix $Z0_{ij}$, as shown in Figure 4 (a)) is first processed by the algorithm to divide the color minimum region, and the color information of each part of the region can be extracted separately as well as saved in a new matrix of size i*j, noted as matrices $Z1_{ij}$, $Z2_{ij}$, Zn_{ij} (as shown in Fig. 4(b)), where each part of the divided region is composed of one single continuous weft yarn. (For the segment filling insertion fabric, its area division standards mainly follow the shortest floating line, as well as the principle of the shortest entanglement, which involves a complex process issue, not discussed in detail in this paper.)

The original pattern image is analyzed by algorithms written in python, in this paper, the simulation model of the segment filling insertion fabric is mainly obtained by connecting the key points with Cubic Hermite spline, so the calculation of the key points in the 3D coordinate system is the core of this study.

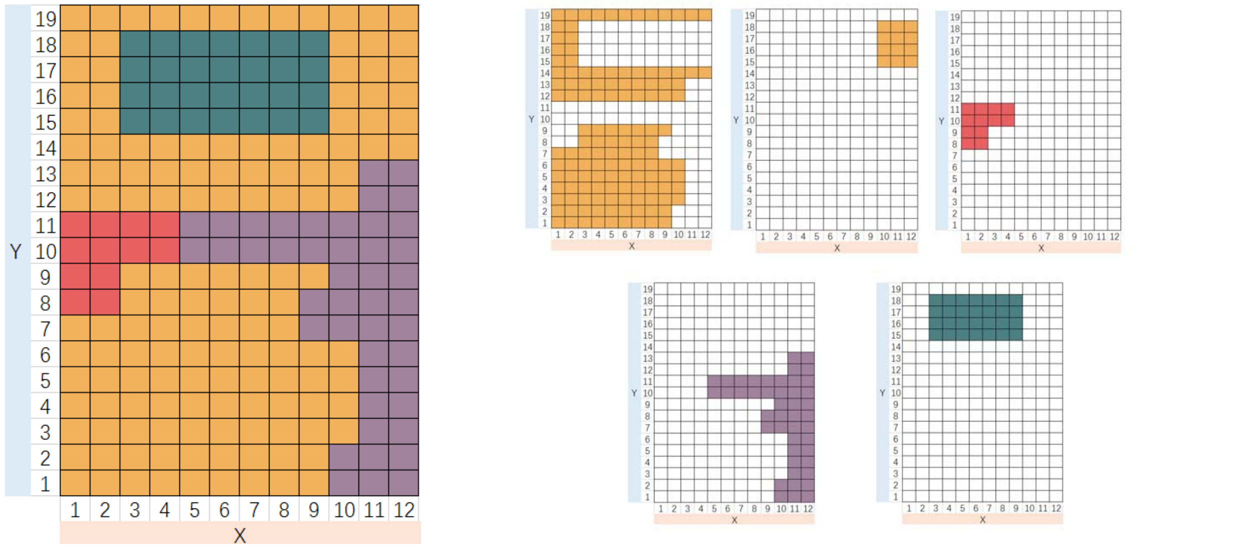
The new matrix obtained by the algorithm fills the divided area with plain organization, noted as $Y1_{ij}$, $Y2_{ij}$, …, Yn_{ij}, the matrix indicates the corresponding relationship between warp and weft in each row, the figure '△' is '1' in the matrix, i.e., the weft is on top; '○' corresponds to the matrix '-1', i.e., the weft is at the bottom; the blank is '0', i.e., the weft does not pass through the region, as shown in Figure 5, this matrix represents the topological information.

$Y1_{11} = 1$, $Y1_{21} = -1$, …, the non-zero region of this matrix is the range covered by the weft, i.e., a continuous yarn coverage, moreover, the key points of the yarn are recorded in the matrix Weft1[P()], where the coordinates of the key point $P(X_P, Y_P, Z_P) = (i, j, Yn_{ij})$. The weave diagram is produced.

The coordinates of the weft at the last point of the previous row are marked as $P(X_P, Y_P, Z_P)$, the adjacent row of wefts (as shown in Figure 6(a)), or the non-adjacent row of wefts (as shown in Figure 6(b)). The starting point is Q.

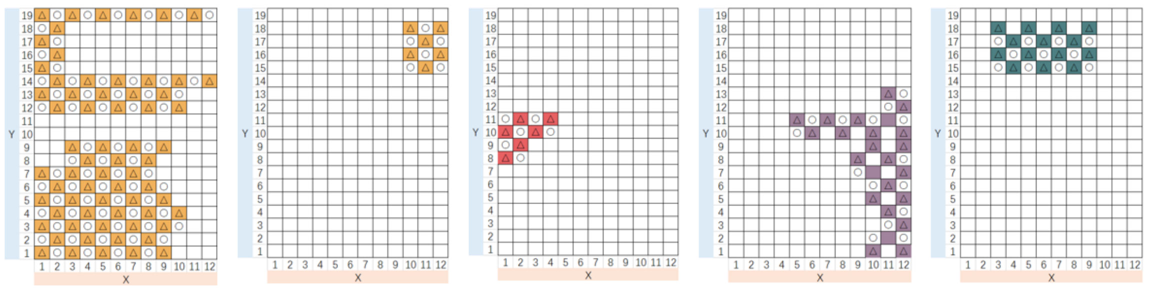
The correct order of the key points is obtained by judging from Eq. 1. As shown in Figure 7.

$$Q = \begin{cases} Q_m, X_P \le X_{Qm} \\ Q_m, X_{Qm} < X_P < X_{Qn} \cup (X_p - X_{Qm})^2 - (X_p - X_{Qn})^2 \le 0 \\ Q_n, X_{Qm} < X_P < X_{Qn} \cup (X_p - X_{Qm})^2 - (X_p - X_{Qn})^2 > 0 \\ Q_n, X_{Qn} \le X_p \end{cases} \quad (1)$$



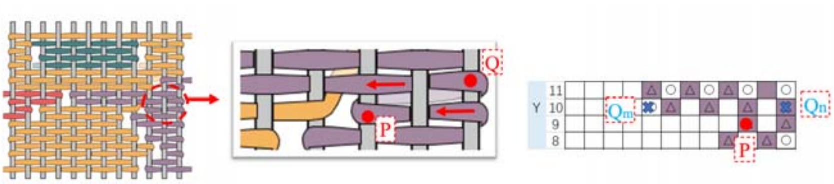
(a) Original Pattern (b) Extract the same color block area and divide it into suitable zones

Figure 4. Original Pattern and the divided zones.

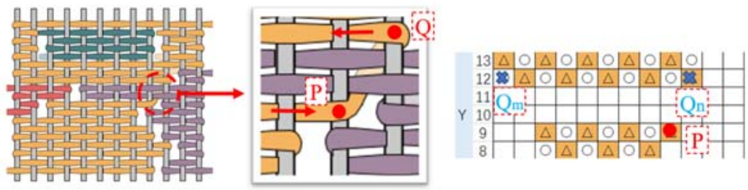


(a) Weft Yarn I(Y1) (b) Weft Yarn II(Y2) (c) Weft Yarn III (Y3) (d) Weft Yarn IV (Y4) (e)Weft Yarn I V(Y5)

Figure 5. The weave diagram of each weft.

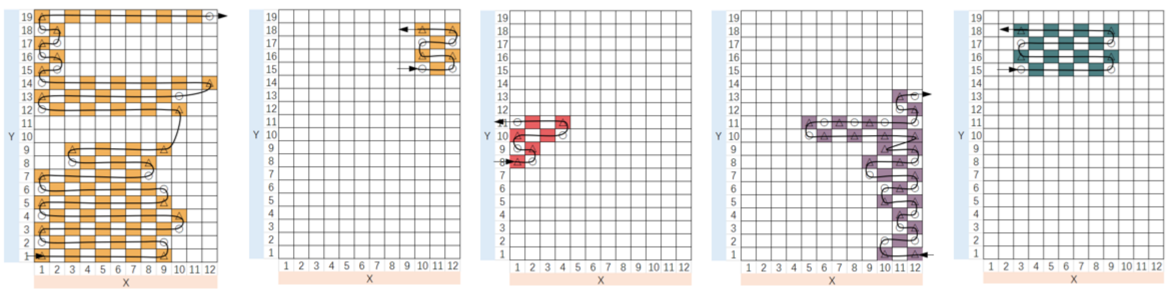


(a)Two points are on adjacent rows



(b) Two points are not on adjacent rows

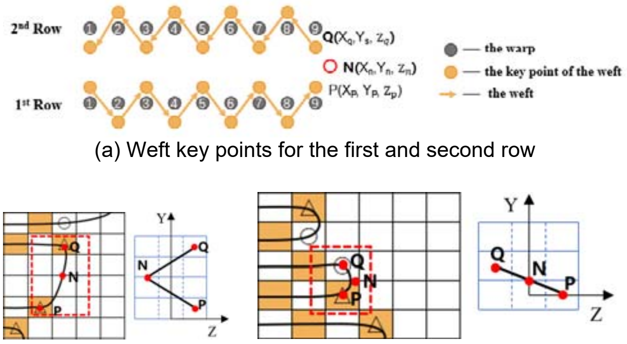
Figure 6. Connection of P and Q.



(a) Weft Yarn I(Y1) (b) Weft Yarn II(Y2) (c) Weft Yarn III (Y3) (d) Weft Yarn IV (Y4) (e)Weft Yarn I V(Y5)

Figure 7. Determine the weft trajectory.

The weft yarn is continuously between rows, so the weft returned from the edge of the fabric. or create a floating line from one point (at the end of the previous row) to another point (the connection of the next row), which is another unique feature of the segmental filling insertion fabric. In the case of the weft return from the edge of the fabric, it is assumed that the next point is Q_n, i.e., a new control point $N(X_N, Y_N, Z_N)$ needs to be inserted between the points $P(X_P, Y_P, Z_P)$ and $Q(X_Q, Y_Q, Z_Q)$ (as shown in Fig. 8). Thereby ensuring the trajectory variation of the yarn in the z-axis direction.



(a) Weft key points for the first and second row

(b) Weft insertion across rows

(c) Weft insertion does not across rows

Figure 8. Insert a new control point N based on Points P and Q.

If the floating line is generated, i.e., a new control point N needs to be inserted between points P and Q, meanwhile, the Z coordinates of points P and Q are also to be compared, then the coordinates of the N point can be calculated.

$$\begin{cases} X_N = \frac{X_P+X_Q}{2} \\ Y_N = \frac{Y_P+Y_Q}{2} \\ Z_N = \begin{cases} \frac{Y_P+Y_Q}{2}, Z_P * Z_Q < 0 \\ -\frac{Y_P+Y_Q}{2}, Z_P * Z_Q > 0 \end{cases} \end{cases} \quad (2)$$

Meanwhile, the next weft is determined by calculating the relative position in the X-axis, followed the Eq. 2, starting from the left or right.

Finally, we got the key points of the yarn recorded in the matrix, suppose the yarn starts from (m,n) and ends at (w,v), the points through the yarn was saved in order in the matrix Weft1 = [$P1(X_m, Y_n, Z_P)$, $P2(X_{m+1}, Y_n, Z_P)$,…, $Pi(X_i, Y_n, Z_P)$, $N(\frac{X_P+X_Q}{2}, \frac{Y_P+Y_Q}{2}, Z_N)$, $P(X_Q, Y_Q, Z_Q)$,…, $P(X_w, Y_v, Z_P)$]. Moreover, all the simulation information is saved in the fabric matrix as follows, Fab = [Wefts[P1(),P2(),…, Pm()], Warps[P1(),P2(),…, Pn()],yarn parameters map].

Simulation Parameters

In addition to some parameters [19-20] that need to be analyzed from the original pattern, some additional parameters have to be input by the designer to simulate the fabric, as shown in Table 1.

Table 1. Specifications of 3D fabric.

	Input parameters	Output
Yarn parameters	Color map Warp radius r1 Weft radius r2	Simulation file
Fabric parameters	Warp density/ Warp gap Weft density/ Weft gap	

The number of warp and weft can be obtained after analysis the pattern. Meanwhile, the matrix information can be gained by further calculations. Many parameters can be caculated, such as, the warp length can be calculated from the yarn fineness and the size of the pattern. Integration of parameters in python to complete the simulation of the fabric as shown in Fig. 9.

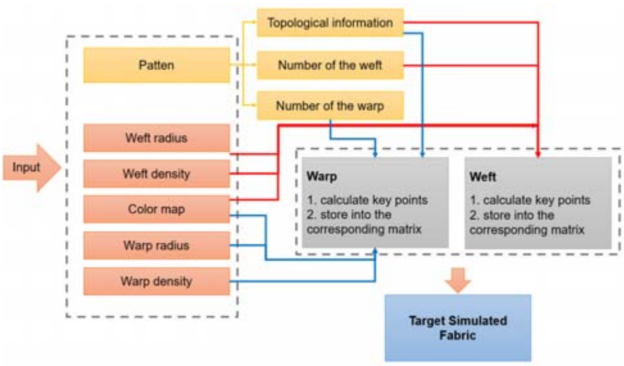


Figure 9. Calling and handling of parameters.

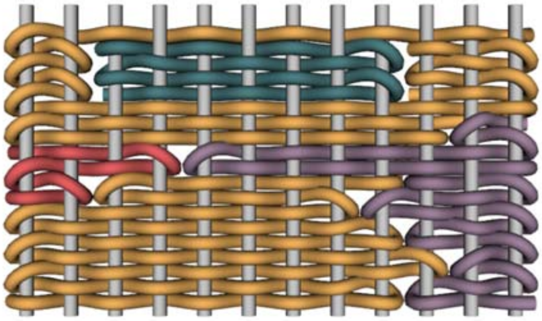
RESULTS AND DISCUSSION

In this study, parameters are collected mainly by analyzing pattern as well as the input from the designer, then the Z-axis coordinates are obtained by filling the segmented area with unit matrix organization, besides, the different rows are connected by inserting auxiliary points; the weft trajectories are obtained from the key point sequence. Finally, yarn parameters are added to complete the simulation of the segmented filling insertion fabric.

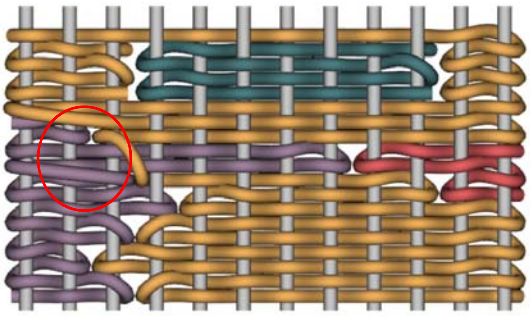
The simulated segment filling insertion fabric is displayed by the TexMind Viewer, as shown in Figure 10. The floating yarns are generated between non-adjacent areas in the back view. Two simulated fabrics with the same warp density but different weft densities are named F1 and F2.

The method proposed in this study, the simulation not only reflected the characteristics of the segment filling insertion fabric but also can be a guide for the fabric design and rationality check of the weaving process. This work solves the following problems in the simulation process: Determination of the sequence point Q in the process of weft yarn transferred to another row; Calculation of the correct auxiliary points by P and Q; The combination of yarn parameters as well as topological information matrix to obtain the simulated fabric.

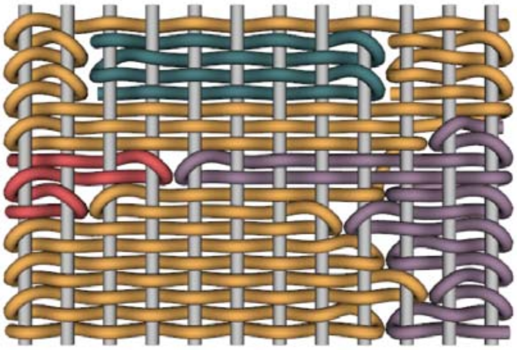
However, the work still has some shortcomings, the bending of warp yarn is not considered in the simulation process and there are details that can continue to be optimized subsequently. More parameters can be added to improve the accuracy of the simulation.



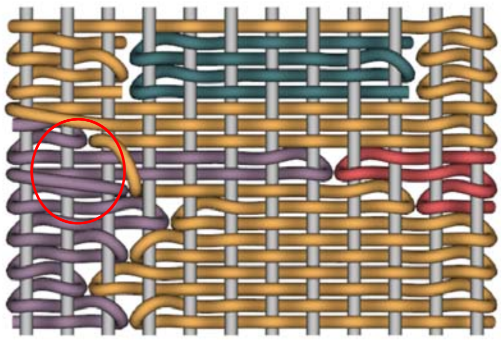
(a) The front view of the simulated fabric (F1)



(b) The back view of the simulated fabric (F1)



(c) The front view of the simulated fabric (F2)



(d) The back view of the simulated fabric (F2)

Figure 10. The front view and the back view of the two simulated fabrics.

CONCLUSIONS

Yarn-level simulation can assist in the design and weaving of the fabric, converting the original 2D weave diagram into a 3D intuitive visual effect, which is very significant for fabric-assisted design. Modeling in 3D visualization at the yarn level is more friendly for the designers, because they can make reasonable modifications to the design by the 3D model. Besides, yarn-level modeling can be also used to simulate the physical properties of textiles.

The structure of the segment filling insertion fabric has infinite possibilities, which can make the fabric more diverse, as different color areas can be woven with different functional yarns.

Acknowledgements: *This research stay in Germany of Jiahui Fang for study was supported by 'the Fundamental Research Funds for the Central Universities' (Grant No.: 2232020E-10) and 'China Scholarship Council'*

REFERENCES

1. Mao X.H, Bao M.(2005) Weaving Volume II. China Textile Publishing House (Beijing).
2. Dong, Z., & Sun, C. T. (2009). Testing and modeling of yarn pull-out in plain woven Kevlar fabrics. Composites Part A: Applied science and manufacturing, 40(12), 1863-1869. https://doi.org/10.1016/j.compositesa.2009.04.019
3. Leaf, J., Wu, R., Schweickart, E., James, D. L., & Marschner, S. (2018). Interactive design of periodic yarn-level cloth patterns. ACM Transactions on Graphics (TOG), 37(6), 1-15. https://doi.org/10.1145/3272127.3275105
4. Jauffrès, D., Sherwood, J. A., Morris, C. D., & Chen, J. (2010). Discrete mesoscopic modeling for the simulation of woven-fabric reinforcement forming. International journal of material forming, 3(2), 1205-1216. http://dx.doi.org/10.1007%2Fs12289-009-0646-y
5. Tripathi, L., Chowdhury, S., & Behera, B. K. (2022). Modeling and simulation of impact behavior of 3D woven solid structure for ballistic application. Journal of Industrial Textiles, 51(4_suppl), 6065S-6086S. https://doi.org/10.1177/1528083720980467
6. Özdemir, H., & Başer, G. (2008). Computer simulation of woven fabric appearances based on digital video camera recordings of moving yarns. Textile Research Journal, 78(2), 148-157. http://dx.doi.org/10.1177/0040517507080692
7. Özdemir, H., & Başer, G. (2009). Computer simulation of plain woven fabric appearance from yarn photographs. The Journal of The Textile Institute, 100(3), 282-292. https://doi.org/10.1080/00405000701757529
8. Fang, J., Ma, Y., Li, Y., et al. (2021). Design and development of urban cultural and creative products with segment filling insertion. In Journal of Physics: Conference Series: 1790(1): 012032. doi:10.1088/1742-6596/1790/1/012032
9. Nilakantan, G., Keefe, M., Bogetti, T. A., Adkinson, R., & Gillespie Jr, J. W. (2010). On the finite element analysis of woven fabric impact using multiscale modeling techniques. International Journal of Solids and Structures,

47(17), 2300-2315. https://doi.org/10.1016/j.ijsolstr.2010.04.029

10. Rief, S., Glatt, E., Laourine, E., Aibibu, D., Cherif, C., & Wiegmann, A. (2011). Modeling and CFD-simulation of woven textiles to determine permeability and retention properties. AUTEX Research Journal, 11(3), 78-83.
11. Kyosev Y. Generalized geometric modeling of tubular and flat braided structures with arbitrary floating length and multiple filaments. Textile Research Journal. 2016;86(12):1270-1279. https://doi.org/10.1177/0040517515609261
12. Kyosev, Y., Topology-Based Modeling of Textile Structures and Their Joint Assemblies, Springer Nature Switzerlang AG, 2019, 238 p, https://doi.org/10.1007/978-3-030-02541-0
13. Dash, B. P., Behera, B. K., Mishra, R., & Militky, J. (2013). Modeling of internal geometry of 3D woven fabrics by computation method. Journal of the Textile Institute, 104(3), 312-321. https://doi.org/10.1080/00405000.2012.720850
14. Wielhorski, Y., Mendoza, A., Rubino, M., & Roux, S. (2022). Numerical modeling of 3D woven composite reinforcements: A review. Composites Part A: Applied Science and Manufacturing, 154, 106729. https://doi.org/10.1016/j.compositesa.2021.106729
15. Manjunath, R. N., & Behera, B. K. (2017). Modelling the geometry of the unit cell of woven fabrics with integrated stiffener sections. The Journal of The Textile Institute, 108(11), 2006-2012. https://doi.org/10.1080/00405000.2017.1308785
16. Lee, S. K., Byun, J. H., & Hong, S. H. (2003). Effect of fiber geometry on the elastic constants of the plain woven fabric reinforced aluminum matrix composites. Materials Science and Engineering: A, 347(1-2), 346-358. https://doi.org/10.1016/S0921-5093(02)00614-7
17. Daelemans, L., Faes, J., Allaoui, S., Hivet, G., Dierick, M., Van Hoorebeke, L., & Van Paepegem, W. (2016). Finite element simulation of the woven geometry and mechanical behaviour of a 3D woven dry fabric under tensile and shear loading using the digital element method. Composites Science and Technology, 137, 177-187. http://dx.doi.org/10.1016/j.compscitech.2016.11.003
18. Liu, H., Kyosev, Y., & Jiang, G. (2022). Yarn level simulation of warp-knitted clothing elements – first results and challenges. Communications in Development and Assembling of Textile Products, 3(2), 115-126. https://doi.org/10.25367/cdatp.2022.3.p115-126
19. Cirio, G., Lopez-Moreno, J., Miraut, D., & Otaduy, M. A. (2014). Yarn-level simulation of woven cloth. ACM Transactions on Graphics (TOG), 33(6), 1-11. https://doi.org/10.1145/2661229.2661279
20. Nilakantan, G., & Gillespie Jr, J. W. (2012). Ballistic impact modeling of woven fabrics considering yarn strength, friction, projectile impact location, and fabric boundary condition effects. Composite Structures, 94(12), 3624-3634. http://dx.doi.org/10.1016/j.compstruct.2012.05.030