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COMPUTER GEOMETRIC MODELING WITH FILAMENT ASSEMBLY MODEL AND CFD SIMULATION OF AIR PERMEABILITY IN KNITTED FABRICS

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A B S T R A C T

This study presents a computational approach for predicting air permeability in knitted fabrics using advanced geometric modeling and computational fluid dynamics (CFD). Two fabric structures 1×1 rib and interlock were modeled using four established filament assembly-based geometric frameworks: Peirce, Leaf and Glaskin, Vassiliadis, and Kurbak. Three-dimensional CAD models of the knitted loops were developed using SolidWorks, incorporating filament-level details. These models were subjected to CFD analysis under standardized test conditions, with unit-cell domains and k-ε turbulence modeling used to simulate airflow. Air permeability results from simulations were compared with experimental data obtained under a 100 Pa pressure differential. Statistical metrics such as MAE, RMSE, and MAPE were applied to evaluate prediction accuracy. Among the models, Kurbak's framework demonstrated the highest correlation with experimental values, yielding the lowest error rates. Furthermore, two-way ANOVA results indicated that fabric type significantly affects prediction accuracy, while the geometric model type had no statistically significant effect. These findings underscore the potential of filament assembly models and CFD in accurately simulating fabric-level air permeability, especially when structural characteristics are properly defined.

1. INTRODUCTION

Structural parameters such as yarn type, diameter, and loop density influence fabric porosity, and thus, its permeability performance can be controlled by managing these factors (Ettehadi et al., 2020). Burleigh et al. (1949) introduced the concept of effective porosity, comprising intrafiber, interfiber, and interyarn porosities, each describing voids within fibers, yarns, and between yarns, respectively. Several studies have aimed to predict the air permeability of woven and knitted fabrics based on these structural characteristics (Ogulata & Mavruz, 2010; Arumugam et al., 2017; Zupin & Hladnik, 2011; Polipowski et al., 2015). With the advancement of 3D

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modeling, researchers have developed geometric representations of knitted loops (Kyosev et al., 2005; Kaldor et al, 2008; Wadekar et al., 2020), along with CAD models of fibers and yarn structures (Sriprateep & Pattiya, 2009; Sriprateep & Singto, 2019; Patumchat & Sriprateep, 2019, 2023; Patumchat et al. 2023), which have also been applied in tensile property prediction (Sriprateep, 2019). CFD techniques have been used to simulate air flow in knitted fabrics at both filament and yarn scales. For instance, Puszkarz and Krucinska (2018) validated CFD simulations with experimental air flow data, and further demonstrated consistency between simulations and thermal insulation tests using mono- and multi-fiber models. Cimilli et al. (2012) and Dehkordi et al. (2017) applied CFD to plain, rib, and interlock knitted fabrics using unit-cell models and turbulence models (k-ε, k-ω) in Fluent, showing high predictive accuracy.

In prior research (Chaikumming et al., 2025) the objective was to develop geometric models of knitted fabric structures in order to predict air permeability through computational fluid dynamics (CFD). The study involved simulations of 1×1 rib and interlock knitted fabrics with varying loop densities, based on plain weft-knitted models constructed using a single-line yarn path approach. This study aims to construct 3D filament assembly models of rib and interlock knitted structures using Peirce, Leaf and Glaskin, Vassiliadis, and Kurbak models within specialized CAD software. CFD simulations are then conducted on unit cells to evaluate air permeability, with results compared against single-line yarn path models and experimental data.

2. MATERIALS AND METHODS

2.1 Materials

Two fabric structures 1×1 rib and interlock patterns were selected for this study, as previously described in the literature (Dehkordi et al., 2017). All knitted fabric samples were produced using a Mayer & Cie® double-jersey circular knitting machine, employing cotton/polyester yarn with a 30-denier count and an average yarn diameter of 0.22 mm. Air permeability measurements were performed using a Shirley Air Permeability Tester, in accordance with the ASTM D737-96 standard. During testing, a constant pressure differential of 100 Pa was applied across the fabric surface. For each sample type, ten repeated measurements were taken to ensure reliability. A summary of the structural and physical properties of the tested knitted fabrics is presented in Table 1.

2.2 Geometry of plain-knitted loop

Numerous geometric models have been developed to represent plain knitted fabrics, as reported by several researchers (Chaikumming et al., 2025; Peirce, 1947; Leaf & Glaskin, 1955; Kurbak., 1998; Kurbak & Ekmen., 2008; Vassiliadis et al., 2007). In addition to modeling basic structures, some studies have extended these models to capture more complex knitted configurations. The development of such geometric representations is driven by several objectives: (a) to identify the factors contributing to dimensional changes during fabric relaxation; (b) to assist in fabric planning and production prior to the knitting process; (c) to support the use of knitted fabrics in technical textile applications; (d) to enable computer-based simulations for design optimization and flaw detection; (e) to evaluate the surface properties of knitted fabrics; and (f) to serve as foundational tools for constructing physical or digital fabric models. The structural characteristics and modeling principles of the Peirce, Leaf and Glaskin, Vassiliadis, and Kurbak models have been thoroughly detailed in earlier publications (Chaikumming et al., 2025).

2.3 CAD Model

The proposed approach comprises three main stages.

• In the first stage, the centerline position of the yarn was calculated based on the geometric model equations and then a two-dimensional (2D) model of the yarn cross-section in weft-knitted fabric structures is constructed, based on the concept of virtual locations as introduced in previous studies. These virtual locations represent the spatial positions of individual filaments, defined by a two-dimensional distribution function. A sequence of yarn cross-sections is generated at uniform intervals along the yarn's axial length. To incorporate yarn twist, each cross-section is rotated incrementally relative to the preceding one, based on a predefined twist parameter.

• The second stage involves the three-dimensional (3D) geometric modeling of knitting loop structures. The configuration of the fibers between any two consecutive cross-sections is approximated using non-uniform rational B-splines (NURBS). The generation of these curves is governed by the twist and spatial trajectory of each fiber, which is determined from the centerline of the yarn path.

• In the third stage, a complete CAD model is constructed. Each fiber geometry is created by sweeping a closed cross-sectional curve along its respective yarn path, allowing for the precise representation of fiber-level structures within the knitted loop.

Table 1. Structural and physical parameters of knitted samples (Dehkordi et al., 2017).

Sample code	Pattern	Wale/cm	Course/cm	Thickness (mm)	Weight (g/m^2)
R1	1x1 Rib	9	11	0.56	130.82
R2	1x1 Rib	9	13	0.58	134.61
R3	1x1 Rib	9	14	0.63	151.23
I1	Interlock	9	11	0.70	278.04
I2	Interlock	11	16	0.79	246.70
I3	Interlock	11	18	0.81	264.14

2.4 CFD analysis

To develop the CFD model, a unit cell from each knitted fabric sample was extracted and modeled using SolidWorks based on a filament assembly structure with three variations in wale and course set densities. CFD simulations were performed in SolidWorks Flow Simulation, where each unit cell was placed inside a pipe-like domain, 5 mm from both inlet and outlet boundaries to ensure fully developed airflow. The use of a unit cell significantly reduced computational time while maintaining analysis accuracy. The k-ε turbulence model, a two-equation Eddy Viscosity Model (EVM), was employed to solve the RANS equations, accounting for turbulent kinetic energy (k) and its dissipation rate (ε). A pressure differential of 100 Pa, matching experimental conditions, was applied across the fabric surface.

3. RESULTS AND DISCUSSION

3.1 CAD modeling of knitted fabric

To construct a detailed 3D geometric model of knitted fabric structures, the methodology involved several sequential stages. First, the geometrical parameters of the knitted loops were derived using four well-established theoretical models: Peirce's model, Leaf and Glaskin's model, Vassiliadis's model, and Kurbak's model. These parameters, which define the shape and spatial configuration of the loops, served as the input for computer-aided design (CAD) modeling. The modeling process focused on two specific knitted fabric types: 1×1 rib and interlock structures. For the rib fabrics, three different combinations of set densities were used, specifically wale/course densities of 9/11, 9/13, and 9/14 (wales per centimeter/courses per centimeter). Similarly, for the interlock fabrics, the selected density combinations were 9/11, 11/16, and 11/18 (Table 1). These combinations yielded a total of six unique density configurations, and when applied across the four loop models, resulted in 24 distinct geometric configurations. In all cases, the yarns used in the wale and course directions had identical linear densities and were made from the same material composition, ensuring consistency in the simulation parameters. The CAD modeling was conducted using SolidWorks software, where in each knitted structure was represented using a filament assembly model that shown in Figure 1. These geometric models were then prepared for computational fluid dynamics (CFD) simulations. Figure 1 illustrates a representative single-unit cell of the fabric structure generated in SolidWorks. This unit cell approach not only ensured geometric accuracy but also helped reduce computational cost during simulation.

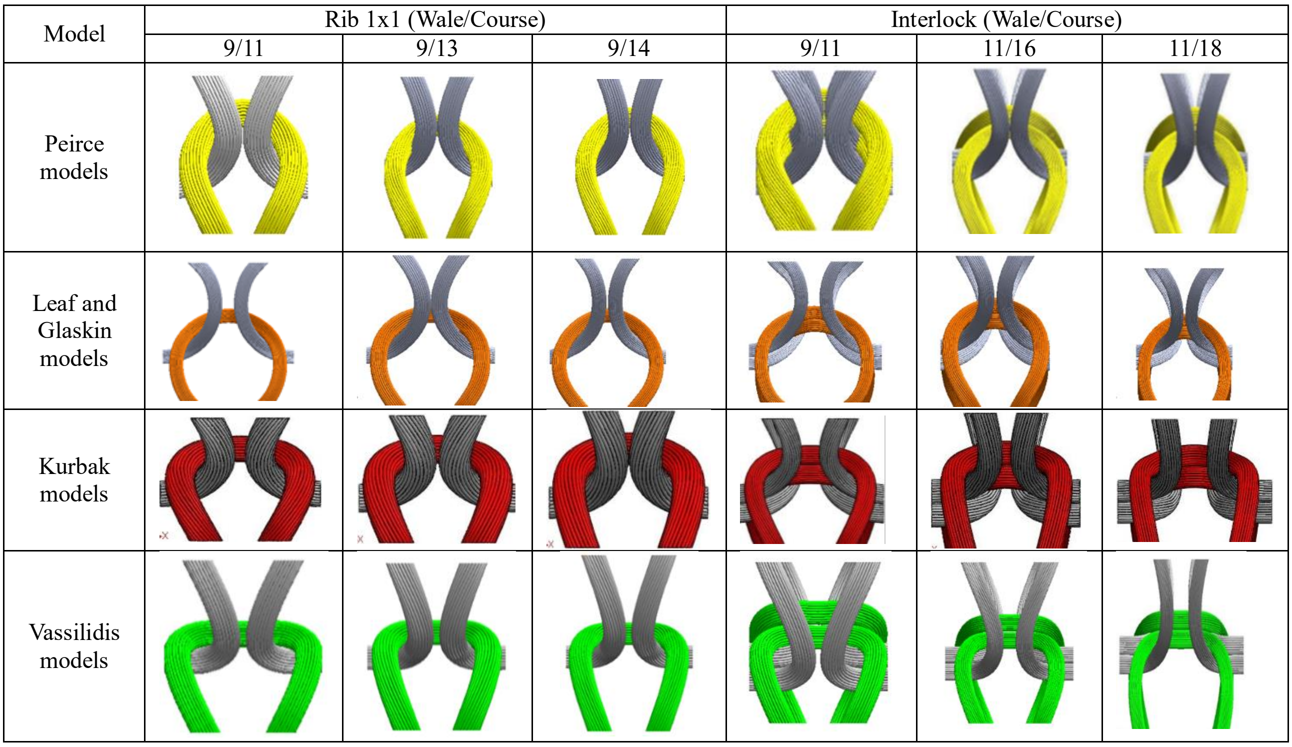

Figure 1. Fabric structure designed of yarn path for rib 1x1 and interlock in 1 unit cell (Peirce models, Leaf and Glaskin models, Kurbak models and Vassilidis models).

3.2 CFD Modeling of knitted fabric

Based on the previously described boundary conditions for airflow simulations, air permeability was analyzed using filament assembly models. The air permeability value (R) was calculated using the equation: R = Q / At, where At represents the tested fabric area, and Q denotes the airflow rate measured by an air permeability tester. Air permeability is defined as the velocity of air passing through the fabric. Figure 2 presents the simulation results of the velocity fields for all fabric models, illustrating how air flows from the inlet to the outlet due to the pressure difference across the fabric. As the airflow encounters the knitted structure, it is redirected toward the pore regions to penetrate the fabric, which consequently increases the airflow velocity. Upon exiting the fabric, the airflow resumes a more linear trajectory. This behavior is clearly depicted in Figures 2(a) to 2(d). A reduction in pore size, caused by an increase in loop density, leads to lower air permeability. Table 2 summarizes the predicted air permeability values for the four knitted fabric models, alongside the corresponding experimental results and percentage errors. Among the four models, the Kurbak model yielded the lowest prediction error, followed by the Peirce model, the Leaf and Glaskin model, and the Vassiliadis model, respectively. Although all simulation models predicted higher air permeability values than the experimental data, the results showed strong agreement between predicted and observed values. Using actual structural parameters of rib 1×1 and interlock knitted fabrics, with defined wale and course densities, contributed to a more accurate simulation of the fabric geometry. These findings support the application of computational fluid dynamics (CFD) in predicting the air permeability of knitted fabrics.

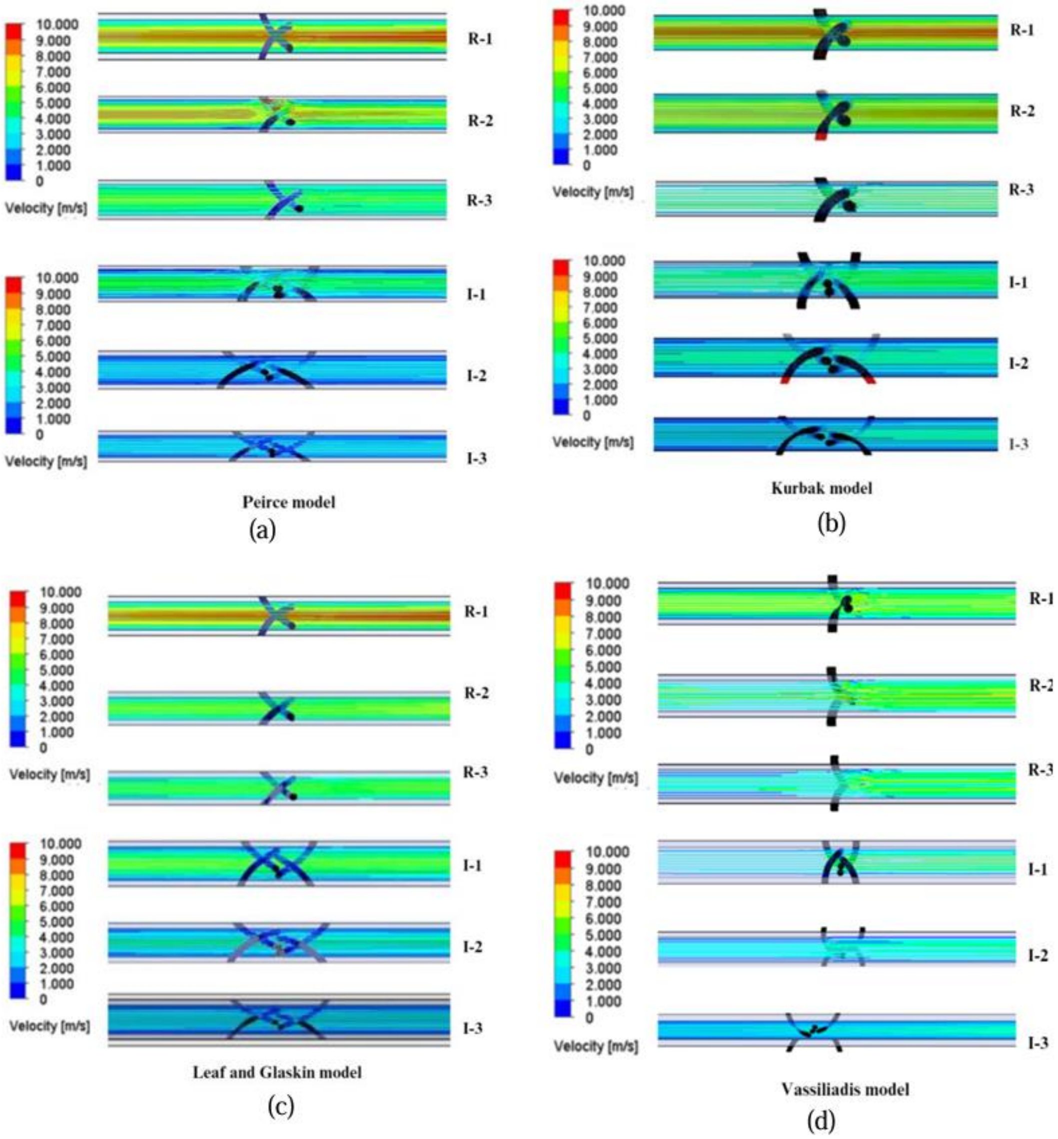

Figure 2. Velocity counters; (a) Peirce models, (b) Leaf and Glaskin models, (c) Kurbak models and (d) Vassilidis models

Table 2. Prediction model of filament assemble model, experimental air permeability results and % error

Fabric type	Experimental air permeability results (ml/s.cm2)	Prediction air permeability results (Filament assemble model) (m^3/s)				Error of air permeability results (%) (Filament assemble model)			
		Peirce model	Leaf and Glaskin model	Kurbak model	Vassiliadis model	Peirce model	Leaf and Glaskin model	Kurbak model	Vassiliadis model
R-1	364	383.1	396.4	381.6	379.6	5.2	8.9	4.8	4.3
R-2	321	346.7	346.6	327.1	345.9	8.0	8.0	1.9	7.8
R-3	290	311.7	310.6	309.1	313.1	7.5	7.1	6.6	8.0
I-1	275	254.6	295.0	287.6	296.1	7.4	7.3	4.6	7.7
I-2	156	164.6	167.3	158.4	156.9	5.5	7.2	1.5	0.6
I-3	140	147.6	151.3	149.8	147.3	5.4	8.1	7.0	5.2

3.3 Statistical Assessment of Air Permeability Prediction

Evaluation or analysis of results by applying statistical principles has been widely used in many fields (Montgomery & Runger., 2011; Sriprateep et al., 2011; Songsorn et al., 2016). This study examines the predictive accuracy of four filament assemble models—Peirce, Leaf and Glaskin, Kurbak, and Vassiliadis—for air permeability in knitted fabrics. Experimental data from six samples (three Rib, three Interlock) were compared with simulation results which illustrates in Table 2. Model performance was evaluated using MAE, RMSE, and MAPE that shows in Table 3. The Kurbak model showed superior accuracy across all metrics (MAE = 11.27, RMSE = 12.73, MAPE = 4.41%). A two-way ANOVA was performed to assess the statistical effects of fabric type and model type on absolute prediction error. Results revealed a significant effect of fabric type (F = 14.06, p = 0.0018), but no significant effect from geomatric model type (F = 2.01, p = 0.153) or their interaction (F = 0.27, p = 0.849). This suggests that the structural characteristics of the fabric (Rib vs Interlock) have a greater influence on prediction accuracy than the choice of model. The consideration of fabric type is crucial when simulating air permeability in knitted fabrics. The Kurbak filament assemble model is recommended for its overall robustness and lower error metrics.

Table 3. Displays the tolerance values of filament assemble type models.

Model type	Standard statistical metrics		
	MAE	RMSE	MAPE (%)
Peirce	17.18	18.45	6.51
Leaf and Glaskin	20.20	21.54	7.76
Kurbak	11.26	12.73	4.40
Vassiliadis	15.48	17.77	5.58

4. DISCUSSION

In a study by Chaikumming et al. (2025), a computer geometric model and CFD simulation of the air permeability of knitted fabrics using a single-line model were developed, and it was found that the simulation using a filament assembly model was much more accurate than the single line model. An increase in loop density leads to smaller pore sizes in the fabric, resulting in reduced air permeability. Interlock structures, consisting of two interlaced layers, demonstrate lower permeability than rib structures due to decreased porosity—illustrated by comparisons such as R-1 versus I-1. The overlapping of loops in interlock designs contributes substantially to this effect. Table 2 compares experimental and simulated results, highlighting structural differences. Unal et al. (2012) reported a strong negative correlation between yarn hairiness and air permeability in single jersey fabrics. Increased hairiness increases fiber-air friction, reducing permeability. In this study, yarn hairiness was not considered, which may partly account for differences between experimental and simulated values. Real textile structures involve additional complexities.

5. CONCLUSION

This research successfully demonstrates the application of 3D computer geometric modeling and CFD simulations for evaluating air permeability in weft-knitted fabrics. By integrating filament assembly models with CAD and flow simulations, the study offers an effective method for analyzing airflow behavior through complex textile geometries. The simulation results closely aligned with experimental data, particularly when using the Kurbak model, which exhibited superior predictive accuracy across all evaluated metrics. Statistical analysis confirmed that fabric structure (rib vs interlock) plays a critical role in prediction error, while differences among the geometric models were not statistically significant. These insights emphasize the importance of accurate structural representation in enhancing the reliability of simulation outcomes. Future research should explore the inclusion of factors such as yarn hairiness, denting, and dynamic pore deformation to improve the realism and applicability of predictive models in textile engineering.

References:

Arumugam, V., Mishra, R., Militky, J., & Salacova, J. (2017). Investigation on thermo-physiological and compression characteristics of weft-knitted 3D spacer fabrics. *The Journal of the Textile Institute, 108*, 1095-1105. doi.org/10.1080/00405000.2016.1220035.

Burleigh Jr, E. G., Wakeham, H., Honold, E., & Skau, E. L. (1949). Pore-size distribution in textiles. *Textile Research Journal*, *19*(9), 547-555. doi.org/10.1177/004051754901900.

Chaikumming, W., Songart, T., Patumchat, P., & Sriprateep, K. (2025). Computer Geometric Modeling and CFD Simulation of Air Permeability in Knitted Fabrics. *Journal of Information Systems Engineering and Management, 10*, 9–20. doi.org/10.52783/jisem.v10i14s.1989.

Cimilli, S. D., Deniz, E., Candan, C., & Nergis, B. (2012). Determination of Natural Convective Heat Transfer Coefficient for Plain Knitted Fabric via CFD Modeling. *Fibres and Textiles in Eastern Europe, 90*, 42-46.

Dehkordi, H,, Ghane, M,, Abdellahi, SB., Soultanzadeh, B. (2017). Numerical Modeling of the Air Permeability of Knitted Fabric Using Computational Fluid Dynamics Method. *Fibers and Polymers, 18,* 1804-1809. doi.org/10.1007/s12221-017-7238-0.

Ettehadi, Z., Ajeli, S., Soltani, P., & Zarrebini, M. (2020). Experimental and CFD Analysis of Air Permeability of Warp-knitted Structures. *Fibers and Polymers, 21,* 1362-1371. doi.org/10.1007/s12221-020-9258-4.

Kaldor, J. M., James, D. L., & Marschner, S. (2008). Simulating knitted cloth at the yarn level. *ACM TRANSACTIONS ON GRAPHICS, 65*, 1-9. doi.org/10.1145/1399504.136066.

Kurbak, A. (1998). Plain Knitted Fabric Dimensions (Part II). Textile Asia. 29, 36-44.

Kurbak, A., & Ekmen, O. (2008). Basic Studies for Modeling Complex Weft Knitted Fabric Structures Part I: A Geometrical Model for Widthwise Curlings of Plain Knitted Fabrics. *Textile Research Journal, 78,* 198–208. doi.org/10.1177/0040517507082352

Kyosev, Y., Angelova, Y., Kovar, R. (2005). 3D modeling of plain weft knitted structures of compressible yarn. Research Journal of Textile and Apparel. 9, 88–97. doi.org/10.1108/RJTA-09-01-2005-B009.

Leaf, G. A. V., & Glaskin, A. (1955). 43—The geometry of a plain knitted loop. *Journal of the Textile Institute Transactions*, *46*(9), T587-T605. doi.org/10.1080/19447027.1955.10750345.

Montgomery, D. C., & Runger, G. C. (2011). *Applied Statistics and Probability for Engineers.* 5th Edition, John Wiley & Son Inc. New York.

Ogulata, R. T., & Mavruz, S. (2010). Investigation of Porosity and Air Permeability Values of Plain Knitted Fabrics. *Fibres and Textiles in Eastern Europe, 18,* 71–75.

Patumchat, P., & Sriprateep, K. (2019). New computer geometric modeling approach with filament assembly model for woven fabric structures. *The Journal of the Textile Institute, 110,* 50-60. doi.org/10.1080/00405000.2018.1509503.

Patumchat, P., & Sriprateep, K. (2023). Computer geometric modeling approach with filament assembly model for 2× 2 twill woven fabrics structures. *Indian Journal of Fibre & Textile Research, 48*, 132-140. doi: 10.56042/ijftr.v48i2.56166

Patumchat, P., Inthidech, S., Srithep, Y., & Sriprateep, K. (2023). Computer geometric modeling approach with filament assembly model for 2×1 and 3×1 twill woven fabric structures. *AUTEX Research Journal, 23*, 522-531. doi.org/10.2478/aut-2022-0032

Peirce, F. T. (1947). Geometrical Principles Applicable to the Design of Functional Fabrics. *Textile Research Journal. 17,* 123–147. doi.org/10.1177/004051754701700301.

Polipowski, M., Więcek, P., Więcek, B., & Jasińska, I. (2015). Study on Woven Fabric Structure Using 3D Computer Image Analysis for In-Depth Identification of Thread Channels. *Fibres and Textiles in Eastern Europe, 23*, 33−39.

Puszkarz, A., & Krucinska, I. (2018). Modelling of air permeability of knitted fabric using the computational fluid dynamics. *AUTEX Research Journal, 18,* 364–376. doi.org/10.1515/aut-2018-0007.

Songsorn, K., Sriprateep, K., & Rittidech, S. (2016). Grey–Taguchi method to optimize the percent zinc coating balances edge joints for galvanized steel sheets using metal inert gas pulse brazing process. *Advances in Mechanical Engineering, 8*, 1–14. doi.org/10.1177/1687814016651194.

Sriprateep, K. (2019). CAD/CAE for stress–strain properties of a wide range of multifilament twisted man-made filament yarns. *Textile Research Journal, 89,* 204-215. doi.org/10.1177/0040517517741162.

Sriprateep, K., & Pattiya, A. (2009). Computer aided geometric modeling of twist fiber. *Journal of Computer Science, 5,* 221-226. doi.org/10.3844/jcssp.2009.221.225.

Sriprateep, K., Patumchat, P., & Theansuwan, W. (2011). Application of Taguchi Method in the Optimization of Cutting Parameters for Turning Metal Matrix Composite. *Advanced Materials Research,* 189-193, 3056-3060. doi.org/10.4028/www.scientific.net/AMR.189-193.3056.

Sriprateep, K., & Singto, S. (2019). New computer geometric modeling approach with filament assembly model for two-ply yarns structures. *The Journal of the Textile Institute. 110*, 1307-1317. doi.org/10.1080/00405000.2019. 1565619.

Unal, P. G., Üreyen, M. E., & Mecit, D. (2012). Predicting properties of single jersey fabrics using regression and artificial neural network models. *Fibers and Polymers, 13*, 87-95. doi.org/10.1007/s12221-012-0087-y.

Vassiliadis, S. G., Kallivretaki, A. E, & Provatidis, C. G. (2007). Geometrical Modelling of Plain Weft Knitted Fabrics. *Indian Journal of Fibre & Textile Research, 32*, 62-71.

Wadekar, P., Goel, P., Amanatides, C., Dion, G., Kamien, R. D., & Breen, D. E. (2020). Geometric modeling of knitted fabrics using helicoid scaffolds. *Journal of Engineered Fibers and Fabrics, 15*, 1–15. doi.org/10.1177/ 1558925020913871.

Zupin, Z., & Hladnik, A. (2011). Dimitrovski. Prediction of one-layer woven fabrics air permeability using porosity parameters. *Textile Research Journal, 82*, 117–128. doi.org/10.1177/0040517511424529.

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