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Literature overview on AI-based garment sizing systems under a sustainable perspective

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Abstract

The definition of the size chart is an extremely significant aspect for companies in the textile sector, with the aim of maximizing profits and minimizing waste. The aim of this article is to carry out a literature review on clothing sizing systems based on artificial intelligence techniques with a sustainable perspective. The most pertinent documents were identified and selected using the PRISMA methodology, then studied and cataloged based on different dimensions such as the document year, the approach used, the presence of an algorithm, a size chart and an anthropometric database and its related population, the gender, the category. The keywords of the documents were identified and their correlations were studied mainly using the VOSviewer software. Finally, a conceptual cyclic framework was presented as a future research development.

Keywords: Literature Review, Garment Sizing Systems, Artificial Intelligence, Sustainability,

1. Introduction

The optimization of production can take place in different ways within a manufacturing company: in the textile sector, one of the strategies that can be adopted is the optimization of the size chart. This makes it possible to minimize the share of unsold products and any post-purchase returns, in order to maximize revenues and profits. Although it may seem like a very simple operation, the problems encountered in its implementation are many: lack of customer information such as anthropometric data, difficult implementation of an algorithm that allows to effectively optimize sizes considering not only body measurements but also the wearability. Moreover, it is crucial to give the right importance to all body shapes, that deviate from those considered "standard". The inconsistency of sizes between different brands and between garments of the same brand, is not a factor that has a positive effect on the customer at the time of purchase. A key element for textile companies is the minimization of waste: through the optimization of sizes, it is possible to minimize production waste using 3D models that allow to easily test the fit and make changes, eliminating the production of physical prototypes that would remain unused, while as regards the more efficient use of materials, it is possible to use nesting software to make material cuts more efficient.

Inaccurate definition of clothes sizes can open up different scenarios. When purchasing an item of clothing, the customer, after having tried on several sizes and not having found any of them comfortable, can decide not to purchase it; if this situation occurs systematically, there will be a large number of unsold products. In the case of online sales, on the other hand, the consumer relies on the tables entered on the

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purchase site and if, once the garment is worn, the measurements are incompatible, the customer will initiate a return procedure. Both unsold and returned cause economic damage for the company which makes significant loses. In addition, the waste of materials such as packaging and fabrics must be considered for product disposal operations and all harmful CO_2 emissions for return operations. It is clear how defining sizes in the best possible way can be very advantageous both for customers and for manufacturing companies and especially for environmental sustainability.

In the literature, there are research works of considerable importance that demonstrate how it is possible to find an optimal sizing in order to minimize waste from cutting fabrics, even taking into account the wearability of the garment and costs (Xu et al., 2020) or articles that illustrate how to create garments that seek to maximize customer satisfaction as much as possible (Xia and Istook, 2017); however, to the best of our knowledge, there are no literature reviews regarding the implementation of garment sizing systems using artificial intelligence techniques. The present paper is the first that aims to study the current state of the art in order to collect as much information as possible and make research in this area easier.

The remainder of this paper is structured as follows: Section 2 shows the research methodology used to carry out the literature review, which is based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) paradigm. Section 3 concerns the analysis of the retrieved documents. In Section 4, a cyclic framework Is proposed as a future research development. Conclusions are in Section 5.

2. Research methodology and bibliometric analysis

This Section explains the research methodology and the bibliometric analysis, as a first result of the application of the PRISMA paradigm (Moher et al.., 2009).

2.1. Research background

The creation of size charts for clothing has had significant improvements with the introduction of artificial intelligence as there are many aspects that are managed differently than in the past. As regards the analysis of anthropometric data, machine learning algorithms can be used, which allow to define the sizes in a much more accurate way and with the reduction of measurement errors; in particular, genetic algorithms are the most used and versatile as they allow both to optimize size charts based on pre-established objectives and to generate different combinations of sizes, using crossover, selection and mutation processes Xu et al.. (2020). Furthermore, artificial intelligence is able to develop predictive models using a wide range of algorithms such as decision trees or neural networks that aim to estimate size even more accurately. One of the main problems encountered by those who study this topic is the lack of anthropometric data, which are often difficult to find; in this context, artificial intelligence can contribute in various ways such as, for example, using algorithms for the generation of synthetic data, i.e. anthropometric data simulated on the basis of statistical models. Furthermore, another tool is real-time data collection using body scanning tools. Despite this, artificial intelligence has some limitations that must be considered. First, the data must be representative of the target population and is often in short supply limiting the accuracy of size coverage; secondly, it is difficult to take into account all the variations that individuals have with respect to standard measurements, and this can affect the fit of the garments. The other thing to be considered is that artificial intelligence is a technology, a tool, therefore it needs direct human feedback from stylists, states and industry experts employed in the process of creating size charts.

2.2. PRISMA methodology application

This subsection shows both the application and the results of the PRISMA methodology, which is a very recognized approach to carry out literature reviews. First of all, there is the planning phase, where some research questions (RQs) are defined:

- RQ1: How does the use of artificial intelligence impact the creation of size charts for garments?
- RQ2: What are the most popular artificial intelligence methods for defining sizes?
- RQ3: How can artificial intelligence help improve the accuracy and fit of clothing sizes?
- RQ4: What are the successful examples where artificial intelligence has been used to size clothing more accurately and effectively?

Subsequently there are the phases of identification, screening, eligibility, inclusion. With the appropriate combinations of keywords and the application of inclusion/exclusion criteria, the number of articles to be analyzed decreases, thus only the most relevant articles will remain. As a starting point, the query used was the following (Scopus was used as scientific database):

TITLE-ABS-KEY ("clothing size" OR "apparel size" OR "clothes" OR "garment size" OR "size chart" AND ("artificial intelligence" OR "machine learning" OR "data mining" OR "deep learning" OR "neural network"))

At first, 838 articles were identified, belonging to the subject areas in Figure 1.

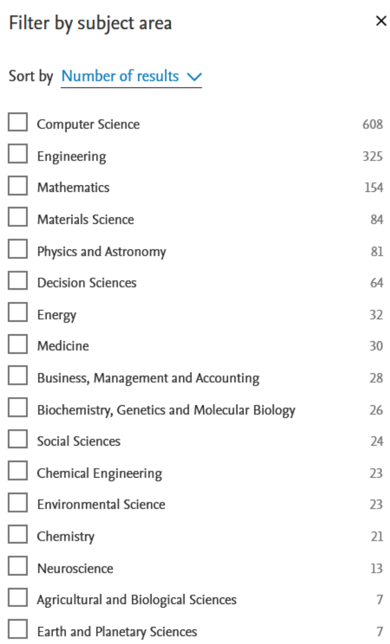

Figure 1. Main subject areas of the first 838 articles (from Scopus)

At this point, after evaluating the quality and reliability of the studies presented, the results of the methodology are shown in Figure 2.

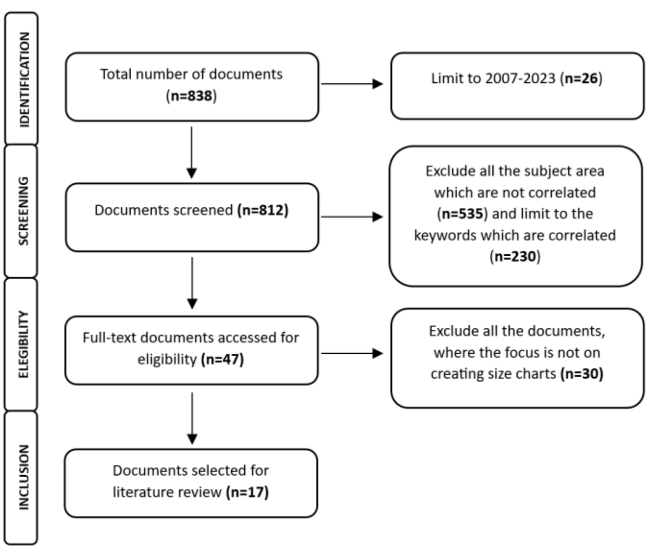

Figure 2. Results of PRISMA methodology

What was done initially was to limit the time span of the articles, it was chosen to exclude articles prior to 2007 as there were no applications related to artificial intelligence; in this way, the articles were reduced to 812. The most significant reduction, however, was the following: all the subject areas that did not have close correlations with the topic covered by this study were excluded, such as physics and astronomy, neuroscience, agricultural and biological sciences and so on, resulting in 277 remaining papers. At this point it was decided to intervene strictly on the keywords used and insert a limitation to those that are closely related, excluding keywords such as "electronic commerce", "gait analysis" and so on, obtaining 47 articles. Excluding all the documents that do not concern the creation of a size chart in detail, 17 articles remain, which will be analyzed below.

2.3. Bibliometric analysis

As far as the type of documents is concerned, it can be seen in Figure 3 that they are mostly journal articles and conference papers.

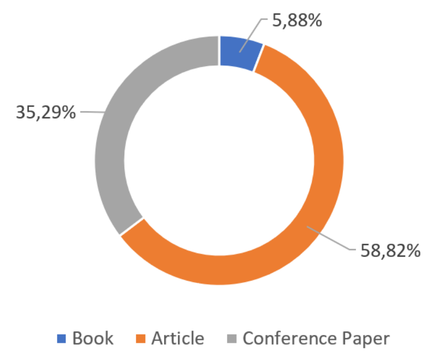

Figure 3. Documents published by type

The countries of origin of the scholars who set out to study the problem mainly come from the Asian continent. In fact, Figure 4 shows that China has a much higher number than other countries followed by Taiwan, Australia, Iran, France and United States.

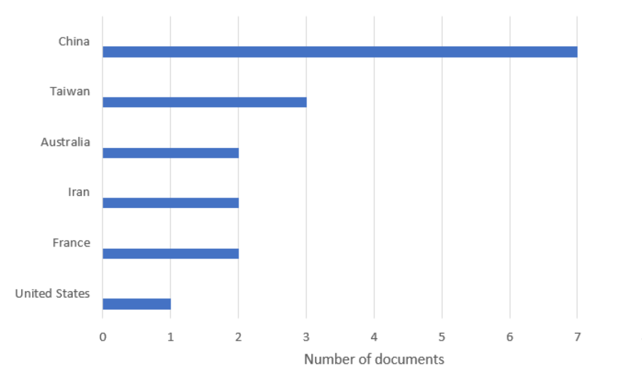

Figure 4. Documents published by country

The VOSviewer tool is commonly used for carrying out quantitative studies about scientific literature (Munir et al., 2022). In this paper, it was used to analyze in detail the links between the keywords of the selected articles, which were divided into clusters. In particular, 10 clusters were identified (Table 1):

Table 1. Clusters and main keywords for each cluster

Cluster	Number of keywords	Main Keywords	Colour
1	25	3D body scan data, anthropometry	Red
2	20	Artificial intelligence, computer science	Green
3	18	Garment sizes, genetic algorithms	Blue
4	16	Classification system, cluster analysis	Yellow
5	15	Mass customization	Purple
6	15	Clothes, apparel industry	Light blue
7	14	Forecasting, virtual garments	Orange
8	14	Commerce, manufacture	Brown
9	13	Data mining, size charts	Lilac
10	6	Clothing sizes and styles	Pink

From Table 2 it can be seen that the clusters with the most items are those relating to artificial intelligence (20) and to some technologies that use it such as 3D body scan data (25); then, there are clusters related to garment sizing, genetic algorithms and cluster analysis.
In Figure 5, the co-occurrence analysis regarding the keywords of the 17 selected documents is shown.

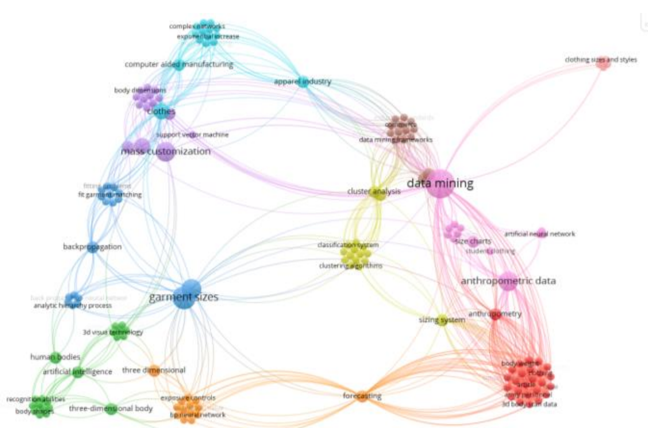

Figure 5. Co-occurrence analysis on all the keywords of the 17 selected documents

What emerges from Figure 5 is the close correlation that exists between the cluster relating to garment sizes and others such as mass customization, forecasting, artificial intelligence and anthropometric data as they are some of the characterizing elements of the creation of a size chart. In this regard, it can be noted that the artificial intelligence cluster is somehow related to forecasting. These clusters are closely related and influence each other as the use of artificial intelligence and anthropometric data can support mass customization while as far as forecasts are concerned, artificial intelligence can analyze historical data to then generate more accurate forecasts. Artificial intelligence, in addition to playing a key role in personalizing garments, can be used to create specific algorithms that support industry experts. Moreover, using data mining techniques it is possible to extract meaningful information starting simply from the data: in the case we are examining, we take into consideration data relating to customer preferences, feedback, body measurements and more. Following the data analysis, it is possible to identify patterns as well as hidden trends and relationships. Another very important cluster, well connected to almost all the others, is that relating to genetic algorithms which are useful for finding optimal solutions to very complex problems. Finally, garment sizes are a fundamental aspect in this sector and the use of anthropometric data analyzed for example with data mining techniques can contribute to their improvement.

3. Document analysis

3.1. Analysis of current state-of-the-art documents

Table 2 summarizes the characteristics of the 17 selected articles. The time span examined starts from 2007 and intensifies from 2011 onwards in correlation with the spread of artificial intelligence techniques. The approaches that have been used vary greatly: from data mining with clustering techniques to optimize the subdivision of sizes to the most innovative 3D technologies useful for scanning bodies and collecting the necessary anthropometric measurements to then carry out the data analysis. Since body measurements vary from country to country, there is considerable interest in the subject in the Asian continent. Articles such as Hsu et al. (2007), Hsu (2009), Majidi et al. (2011), Shahrabi et al. (2013), Rong (2016), Wang et al. (2020a,b,c) used data mining techniques to develop size charts; in particular, many of them used clustering techniques to appropriately subdivide the collected data in order to develop a female size charts for facilitating garment production, improve industrial standards and enhance production, develop a hybrid intelligent model for constructing a size recommendation expert system in textile industries, optimization of apparel size selection for mass customization and so on. As for 3D technologies, they are frequently used in the analyzed articles; in fact in Jianping et al. (2009) it is used as an application of pattern recognition for shirt mass customization, while Yao et al. (2021) uses it to replace the customers' body shape in virtual adaptation, while Gupta and Zakaria (2014) illustrate the benefits of 3D body scanning, computer aided design, and the use of body motion analysis to meet clothing comfort requirements. In Xu et al. (2009) a system for predicting the visible profile of the analyzed garment is developed using various technologies such as body scanners, fuzzy neural networks and OpenGL software.

Table 2. State of art of AI-based garment sizing systems (N.A. - Not Available)

Authors	Year	Document type	Approach	Algorithm	Size chart	Anthropometric database	Country	Category
Hsu et al.	2007	Article	Clustering	N.A.	✓	✓	Taiwan	Female
Hsu et al.	2009	Article	Clustering	N.A.	✓	✓	N.A.	N.A.
Jianping et al.	2009	Conference paper	3D technologies	N.A.	✓	N.A.	China	Male
Xu et al.	2009	Conference paper	Body scanner/BP/fuzzy neural network	✓	✓	N.A.	N.A.	N.A.
Majidi et al.	2011	Article	Clustering	N.A.	✓	✓	Iran	Male
Majidi et al.	2013	Article	Neural networks	✓	✓	✓	N.A.	Female
Shahrabi et al.	2013	Article	Clustering/Neural networks	✓	✓	N.A.	Iran	Male
Ronglei et al.	2014	Article	Neural networks	✓	✓	N.A.	N.A.	N.A.
Gupta and Zakaria	2014	Book	3D/data mining technologies	N.A.	N.A.	N.A.	N.A.	N.A.
Rong	2016	Conference paper	Data mining	N.A.	N.A.	N.A.	N.A.	N.A.
Chen and Xu	2017	Conference paper	Neural networks	✓	✓	N.A.	N.A.	Male
Wang et al.	2020a	Article	Clustering	✓	N.A.	N.A.	N.A.	N.A.
Wang et al.	2020b	Conference paper	Clustering	✓	✓	✓	China	Male
Wang et al.	2020c	Article	Neural networks	✓	N.A.	N.A.	N.A.	N.A.
Yao et al.	2021	Conference paper	3D technologies	N.A.	✓	✓	China	Female
Xu et al.	2021	Article	Multiple linear regression	N.A.	✓	N.A.	N.A.	N.A.
Kolose et al.	2021	Article	Decision tree/3D technologies	✓	✓	✓	New Zealand	Female/Male

4. Future developments: A cyclic framework for size chart

A possible future research development is represented by the implementation of the framework presented in this section, in order to improve the practices of implementing the new size charts or optimizing the previous already existing size charts. By doing so, companies would significantly reduce the percentages of returns from customers or unsold items, without considering production waste which would be further minimized since industry 4.0 allows for the efficient use of resources and the reduction of the environmental impact.

The proposed framework aims to obtain a size chart that is as inclusive and optimal as possible. It is taken for granted that it is necessary to have accurate anthropometric data and, if possible, collected by 3D body scanners as they are very precise and less subject to measurement errors as would happen with other methods of data collection. Once this is done, size categories are defined based on the data available: the number of sizes and the range of values to be considered can be arbitrarily decided. Once this is done, the framework gets to the heart with a further data analysis: the anthropometric data are analyzed and the most relevant ones are selected according to the established standards, thus cleaning the dataset from data deemed obsolete. In this way, the subsequent operation with the most innovative clustering methodologies will be more precise and optimal in the division of data. Before obtaining the size table, KPIs are defined which can be measurable such as the expected return rate of the garments which provides indications on the accuracy of the size table or non-measurable such as the fit on the customer and his/her relative satisfaction. Taking all this into account, the previously obtained clusters are optimized and thus the anthropometric data ranges are obtained for each size. This procedure can be made cyclical by inserting further available data and further KPIs in order to obtain the most optimal sizes possible. Furthermore, different techniques and different technologies can be used according to the needs and availability of the company and the operators.

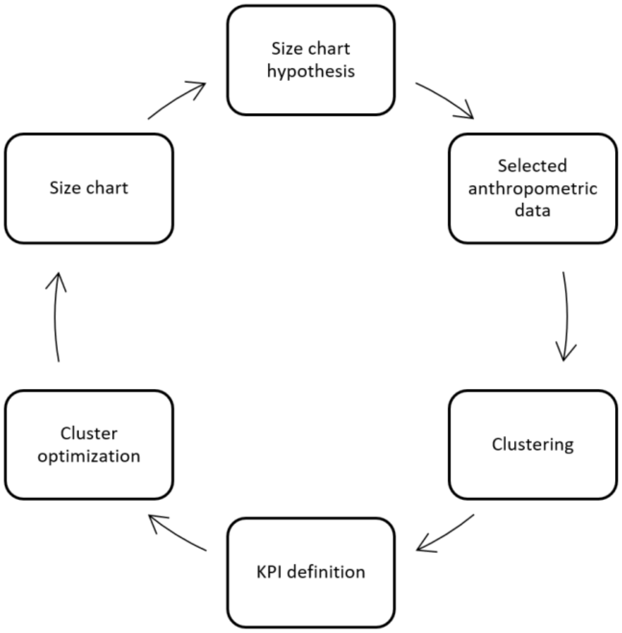

Figure 6. Framework proposed - Conceptual view

This conceptual framework in Figure 6 is innovative as it allows you to take into account some KPIs whose importance is often ignored. For example, with the implementation of genetic algorithms it is possible to take into account KPIs such as the precision of the sizes by evaluating the percentage of correspondence between the sizes generated by the algorithm with the actual anthropometric measurements, the convergence time necessary for the algorithm to reach an optimal solution, the reduction of the number of iterations, the percentage of returns on the total garments sold and the customer satisfaction using surveys and reviews.

5. Conclusions

This article proposed a literature overview on garment sizing systems using AI techniques in the field of Industry 4.0 with a sustainable perspective. After searching for the most relevant articles, the PRISMA methodology was applied to select the most relevant articles and, subsequently, carefully study them according to their characteristics. The correlations between the keywords of the articles were studied using the VOSviewer software, the selected documents were analyzed in detail. Finally, as a future research development, a cyclic AI-based framework was described which allows for the creation of a size chart using anthropometric data and some AI-based techniques such as clustering.

References

Chen, G., & Xu, Z. (2017, July). Shirt Version Intelligent Recommendation for Rapid Garment Customization. In 2017 4th International Conference on Information Science and Control Engineering (ICISCE) (pp. 668-672). IEEE.

Hsu, C. H. (2009). Data mining to improve industrial standards and enhance production and marketing: An empirical study in apparel industry. Expert Systems with Applications, 36(3), 4185-4191.

Hsu, C. H., Lin, H. F., & Wang, M. J. (2007). Developing female size charts for facilitating garment production by using data mining. Journal of the Chinese Institute of Industrial Engineers, 24(3), 245-251.

Jianping, W., Dongping, L., & Fuliang, Z. (2009, May). Application of pattern recognition and 3D visual technology in shirt mass customization. In 2009 Second International Conference on Information and Computing Science (Vol. 2, pp. 345-348). IEEE.

Kolose, S., Stewart, T., Hume, P., & Tomkinson, G. R. (2021). Prediction of military combat clothing size using decision trees and 3D body scan data. Applied Ergonomics, 95, 103435.

Majidi, M.M., Moghadam, M.B., Nourani, G. & Pourtaheri R. (2011). Development of sizing systems for iranian high-school male students. World Applied Sciences Journal, 13:1807-1813.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group*. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Annals of internal medicine, 151(4), 264-269.

Munir, F., Yani, Y. M., Nizmi, Y. E., & Suyastri, C. (2022). State of the art para-diplomacy: a systematic mapping studies and a bibliometric analysis vos viewer in scopus database. Academic Journal of Interdisciplinary Studies, 11(2), 129.

Rong, R. (2015, September). The Exploration and Realization of Clothing Sizes Support System Based on Data Mining. In 2015 Fifth International Conference on Instrumentation and Measurement, Computer, Communication and Control (IMCCC) (pp. 167-170). IEEE.

Ronglei, L., Wenjie, H., & Chengyi, L. (2014). An Algorithm Based on Wavelet Neural Network for Garment Size Selection. TELKOMNIKA (Telecommunication Computing Electronics and Control), 12(4), 1073-1078.

Shahrabi, J., Hadavandi, E., & Salehi Esfandarani, M. (2013). Developing a hybrid intelligent model for constructing a size recommendation expert system in textile industries. International Journal of Clothing Science and Technology, 25(5), 338-349.

Tsai, C. Y., & Hsu, C. H. (2013). Developing standard elderly aged female size charts based on anthropometric data to improve manufacturing using artificial neural network-based data mining. Theoretical Issues in Ergonomics Science, 14(3), 258-272.

Wang, Z. J., Wang, J. P., Zeng, X. Y., & Xing, Y. M. (2020a). Knowledge discovery and data mining-based garment size selection for mass customization. Journal of Fiber Bioengineering and Informatics, 13(3), 113-128.

Wang, Z., Zeng, X., Wang, J., Bruniaux, P., Xing, Y., Chi, C. & Zhang, M. (2020b). Optimization of apparel size selection for mass customization using data mining-based knowledge discovery technique. Textile Bioengineering and Informatics Symposium Proceedings 2020 - 13th Textile Bioengineering and Informatics Symposium, TBIS 2020, 269-277.

Wang, Y. W., Luo, R. L., & Kang, Y. Z. (2020c). Automatic measurement of key dimensions for Han-style costumes based on use of convolutional neural network. Journal of Textile Research, 41(12), 124-129.

Xia, S., & Istook, C. (2017). A method to create body sizing systems. Clothing and Textiles Research Journal, 35(4), 235-248.

Xu, J., Gao, S., & Zhang, W. (2009, December). A Research on Showing Ways of Virtual Garments Profile. In 2009 Second International Symposium on Computational Intelligence and Design (Vol. 1, pp. 28-31). IEEE.

Xu, Y., Thomassey, S., & Zeng, X. (2020). Optimization of garment sizing and cutting order planning in the context of mass customization. The International Journal of Advanced Manufacturing Technology, 106(7-8), 3485-3503.

Xu, Y., Thomassey, S., & Zeng, X. (2021). Machine learning-based marker length estimation for garment mass customization. The International Journal of Advanced Manufacturing Technology, 113, 3361-3376.

Yao, T., Pan, L., Wang, J., & Yao, C. (2021). Research on Somatotype Recognition Method Based on Euclidean Distance. In Advances in Artificial Intelligence, Software and Systems Engineering: Proceedings of the AHFE 2020 Virtual Conferences on Software and Systems Engineering, and Artificial Intelligence and Social Computing, July 16-20, 2020, USA (pp. 242-249). Springer International Publishing.

Zakaria, N., & Gupta, D. (Eds.). (2019). Anthropometry, apparel sizing and design. Woodhead Publishing.