
Estimation of body surface area coverage by garment items: different approaches using mesh base modelling

Gunther Paul* and Leyde Briceno

AITHM,

James Cook University,

475 Bridge Road Mackay QLD 4740, Australia

Email: gunther.paul@jcu.edu.au

Email: leyde.briceno@jcu.edu.au

*Corresponding author

Abstract: Digital human modelling can be applied to determine skin exposure to sun as a factor in modelling risk of skin cancer. To determine body surface area covered by clothing (BSAC), a variety of garment data must be overlaid with the human model. Two approaches, one based on creation of clothing using MakeHuman add-ons in Blender, and the other based on the import of data are exemplified. Results are compared with data from Zhang (Shah and Luximon, 2019). We found that a scalable library of garment elements, assembled to typical apparel is a feasible way to model clothing. We conclude that valid BSAC could be determined.

Keywords: digital human modelling; DHM; body surface area covered by clothing; BSAC; skin cancer; MakeHuman.

Reference to this paper should be made as follows: Paul, G. and Briceno, L. (2022) 'Estimation of body surface area coverage by garment items: different approaches using mesh base modelling', *Int. J. Human Factors Modelling and Simulation*, Vol. 7, Nos. 3/4, pp.329–341.

Biographical notes: Gunther Paul holds a Master's in Mechatronics and PhD in Ergonomics from the TU Darmstadt in Germany. After a Postgraduate Fellowship at the TU Darmstadt for five years, he joined Ford Motor Company in 1999. He developed and managed projects in product development, information technology and manufacturing engineering at the Ford, Faurecia and Daimler until 2009 when he established a laboratory and research group at University of South Australia. From 2012–2017, he was a Senior Lecturer for OHS and Ergonomics at the Queensland University of Technology and Head of Discipline from 2015–2017. He is now an Associate Professor and Principal Research Fellow OHS at the James Cook University. He is chairing the IEA Technical Committee for Human Modeling and Simulation.

Leyde Briceno holds a Master's in Applied Mathematics to Engineering and Industrial Engineering. She has participated in research projects in digital human modelling, bioengineering, and mathematical modelling and simulation of systems. From 2012 to 2016, she was a researcher and Lecturer at the National Institute of Bioengineering, Central University of Venezuela. She is now an Adjunct Research Associate at the Australian Institute of Tropical Health and Medicine, James Cook University.

This paper is a revised and expanded version of a paper entitled 'Estimation of body surface area coverage by garment items: different approaches using mesh base modelling', presented at Human Systems Integration Conference (HSI2019), Biarritz, France, 11–13 September 2019.

1 Introduction¹

MakeHuman, in combination with Blender software is a digital human modelling (DHM) tool which can be applied towards ergonomic modelling (Bastioni et al., 2008; Briceno and Paul, 2018; Buys et al., 2011). It has been found useful to model body surface area covered by clothing (BSAC) (Briceno et al., 2018). DHM tools have been used to reproduce realistic body shapes (Poirson and Delangle, 2013) as well as body and clothing assembled (Briceno et al., 2018; Shah and Luximon, 2019; Dura-Gil et al., 2019; Scataglini et al., 2019; Dove, 2019). Gage et al. (2017) pointed out that due to the large variety of clothing items and styles clothing coverage, it could be assessed using simulation models. Sun-protective clothing provides a physical barrier that reduces the amount of UVR reaching the skin (Harrison and Downs, 2015) and regularly wearing sun-protective clothing may reduce risk of developing skin cancer (Harrison et al., 2005, 2010). Determining BSAC by clothing should be a priority of the garment industry. Consequently, to support the design of garment in its sun-safe specification and to advance the application of DHM methodology in the determination of BSAC, an approach to digitally assess common clothing items is developed by means of the DHM tool MakeHuman v1.1.1 (Bastioni et al., 2008) and Blender software 2.79 (Blender Foundation, <https://www.blender.org>). BSAC by clothing is evaluated using the Bodies Under Flowing Fashion (BUFF) dataset (Zhang et al., 2017), which originally was generated and used for estimating body shape under clothing from 3D scans of real people. The BUFF dataset includes three males and three females in two clothing styles. In this study, four subjects in neutral posture from this dataset were selected and compared with bodies and clothing items reproduced in DHM that matched with the subjects and their outfits.

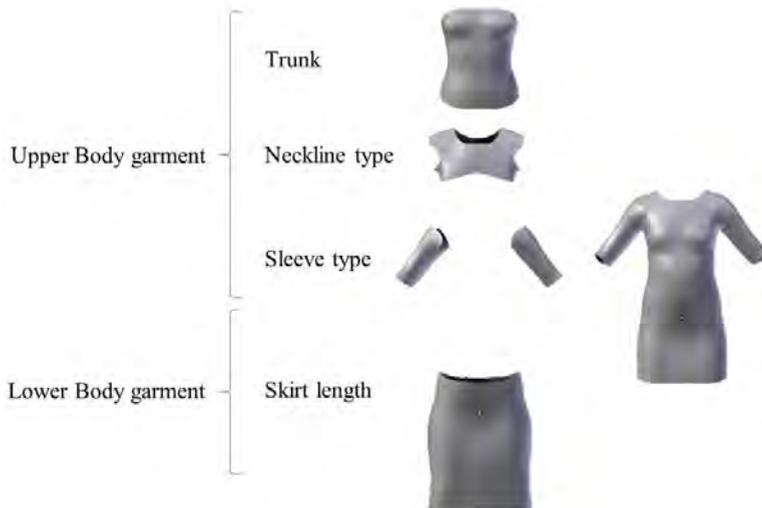
2 Material and methods

2.1 *Clothing library*

The clothing library was created using MakeHuman add-ons (Bastioni et al., 2018) in Blender software (Blender Foundation, <https://www.blender.org>). The body mesh was divided by regions: upper body (neck, trunk and upper limbs) and lower body. Landmarks were used in the process of making clothing.

Templates are composed of upper body garment pieces (trunk, neckline and sleeve types) and lower body garment pieces (trousers and skirt length sizes) which can be assembled in order to create a range of regular clothing types, both for female and male models. Figure 1 shows an exemplary assembly structure of such garment pieces.

Figure 1 Creation of female outfit using upper and lower garment pieces (see online version for colours)



Female gender garment pieces

Upper body items are:

- trunk: strapless, tank, off-shoulders
- neckline: round, turtle and V necklines
- sleeves: short, elbow, 3/4 and long sleeves.

Lower body items are:

- trousers: mini pants, mid-thigh, above the knee, mid-calf, full length trousers
- skirt: mini, above the knee, mid-calf, maxi skirt.

Male gender garment pieces

Upper body items are:

- trunk: base and tank
- neckline: collared shirt, round, turtle and V necklines
- sleeves: short, elbow, 3/4 and long sleeves.

Lower body items are:

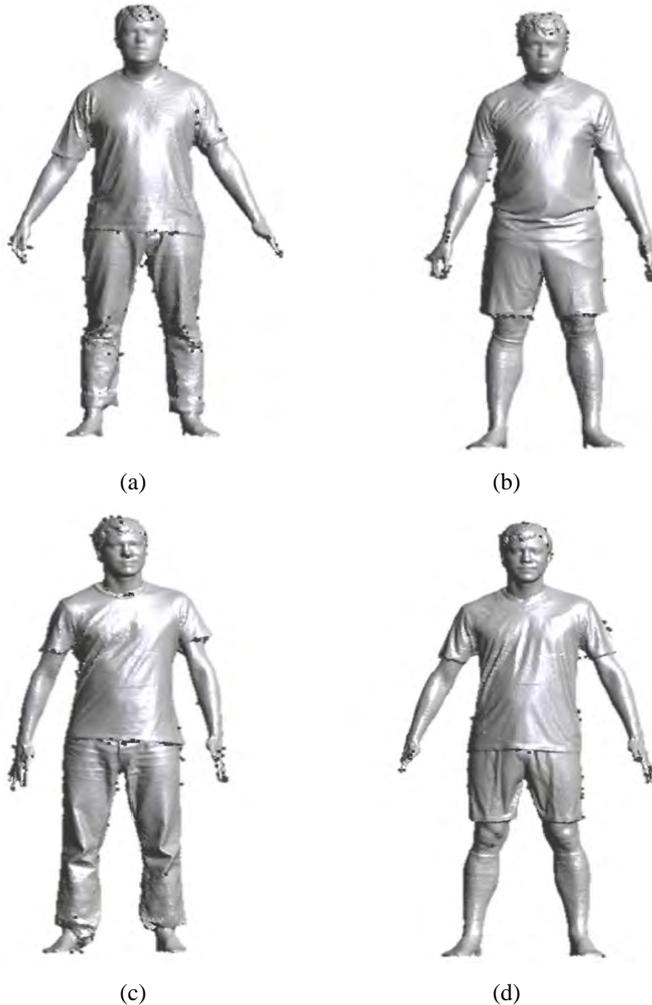
- trousers: mid-thigh, above the knee, mid-calf and full-length trousers.

Materials, textures, and colours were not considered in the clothing library.

2.2 Validation against BUFF dataset

Subjects from the BUFF dataset (Zhang et al., 2017) were selected (two males and two females) wearing two outfits (Figures 2 and 3) for validation.

Figure 2 BUFF dataset*: male gender, (a)–(b) subject 1 and (c)–(d) subject 2 wearing (a) and (c) t-shirt and long trousers and (b) and (d) a soccer outfit

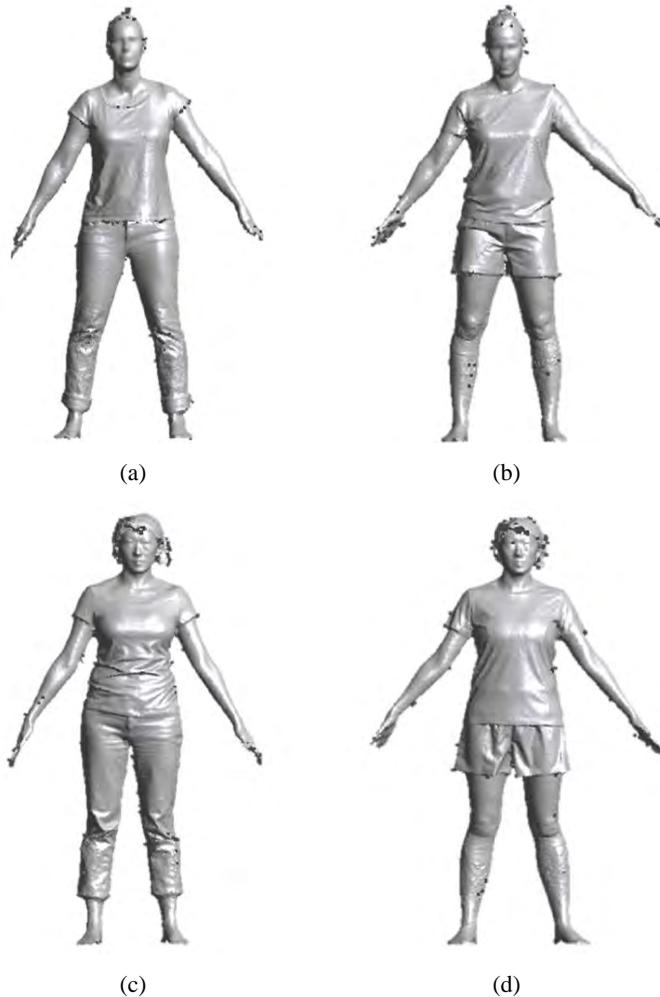


Source: *Harrison and Downs (2015)

2.2.1 Body surface area calculation

Subjects selected in the BUFF dataset were reproduced as DHM using MakeHuman software. The body statures were measured using MeshLab software (Cignoni et al., 2018). Circumferences were calculated as the perimeter of an ellipse where minor and major diameters were determined using the GiD graphical pre-processor (CIMNE, Campus Nord UPC).

Figure 3 BUFF dataset*: female gender, (a)–(b) subject 1 and (c)–(d) subject 2 (a) and (c) wearing t-shirt and long trousers and (b) and (d) a soccer outfit



Source: *Zhang et al. (2017)

For the reproduced bodies, the body surface area not covered by clothing (BSANC) were calculated following the procedure proposed in Buys et al. (2011) using Blender. For the BUFF dataset meshes, the BSANC were determined using MeshLab software (Cignoni et al., 2018).

Upper and lower body garment pieces from the clothing library were employed for Figures 2(a), 3(a), 2(c) and 3(c), and additional pieces were generated for the soccer outfit [Figures 2(b), 3(b), 2(d) and 3(d)].

To facilitate comparison with the BUFF dataset models, the DHM subjects reproduced using MakeHuman software were scaled from (dm^2) to (mm^2) using Blender software. They were then imported into MeshLab and aligned by means of translations and rotations.

2.3 Patterns

Using Blender software, MakeHuman add-ons and the ‘atomic boy’ pattern (Atomic Playwear), a preliminary procedure was carried out to adjust the UV coordinate map to a real-world pattern using UV Blender tools (Blender Nation, <https://www.blendernation.com/2018/02/18/magic-uv-v5-0-released/>). In this approximation, seams were marked to reflect the separation in a real-world pattern. The data generated was subsequently unwrapped and UV groups were adjusted until the UVs overlaid the pattern. In the last step, the UV layout was exported.

3 Results

Using the clothing library, proposed upper and lower body garment pieces can be combined to create different outfits for female (Figure 4) and male models (Figure 5).

Figure 4 Garments for females using the clothing library (see online version for colours)



Figure 5 Garments for males using the clothing library (see online version for colours)



The BUFF dataset bodies reproduced were visually overlaid and compared with the original meshes (Figures 6 and 7) whilst BSANC for the bodies selected were calculated (Table 1).

Figure 6 Male gender, subject 1(b), soccer outfit



Figure 7 Female gender, subject 1(a), t-shirt and long trousers

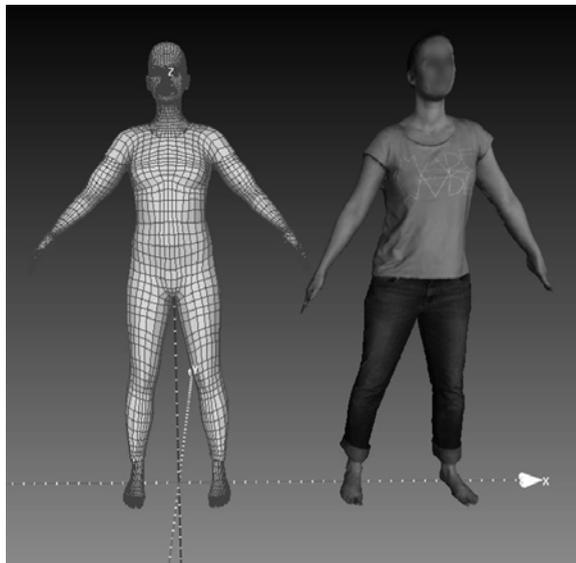


Table 1 BUFF reference dataset and DHM bodies reproduced: BSANC

Gender	Model	BUFF dataset	DHM library	Error
		BSANC (dm ²)	BSANC (dm ²)	%
Male	a	39.94	39.92	-0.06
	b	49.29	50.98	3.43
	c	42.71	41.92	-1.86
	d	52.00	53.16	2.23
Female	a	54.28	54.09	-0.36
	b	62.73	59.63	-4.95
	c	54.37	52.81	-2.87
	d	58.94	57.62	-2.24

3.1 Validation BUFF vs. DHM library data

To validate, reproduced bodies with their clothing combination were used to calculate surfaces (BSANC) and compare against the reference BUFF dataset.

When comparing DHM generated datasets with selected datasets from Zhang et al. (2017), the calculated BSANC error remained within $-5\% < \epsilon_1 < +3.5\%$, with the largest errors for both male and female subject 1 occurring in a soccer outfit (male: +3.43%; female: -4.95%). Overall, the absolute average error was $|\epsilon|_{avg} = 2.25\%$ (male: 1.895%; female: 2.605%).

3.2 Comparison with real-world pattern

A pattern (Figure 8) and garment (Figures 9 and 10) were generated by comparing and adjusting the model using the atomic boy pattern and Blender tools.

Figure 8 Atomic boy mesh base pattern generated by means of UV Blender tools

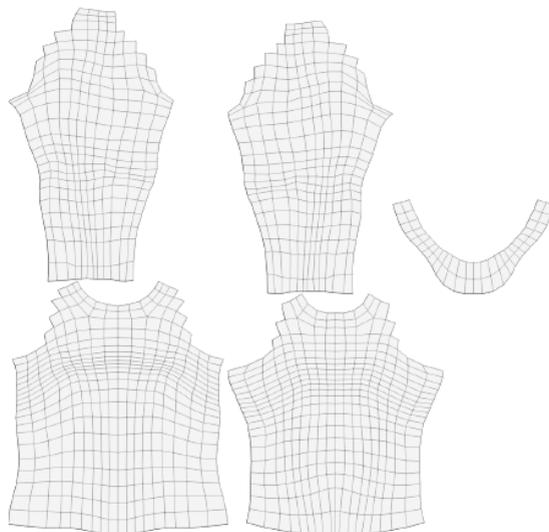


Figure 9 8 yr. old child body and atomic boy shirt reproduced and assembled in DHM (see online version for colours)

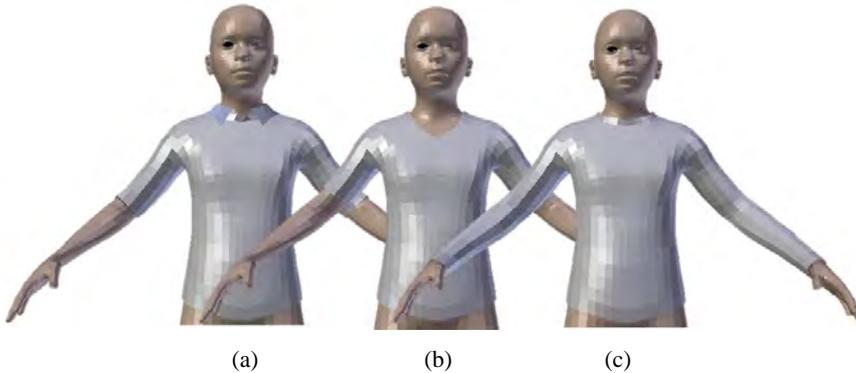


Figure 10 Atomic boy shirt (a) top, (b) back, (c) front and (d) right views (see online version for colours)



A virtual human body was generated using MakeHuman for a child of male gender and a stature of 125 cm with normal weight. By means of the clothing library, three upper body garments (collared shirt, V and crew necklines and elbow, short and long sleeves) were created and assembled to the body (Figure 11).

Figure 11 Outfits, (a) collared shirt neckline and elbow sleeve (b) V neckline and short sleeve (c) crew neckline and long sleeve (see online version for colours)



BSANC was calculated for the outfits shown in Figures 11(a), 11(b) and 11(c) and the atomic boy shirt labelled here as ‘(d)’ for reference (Figures 9 and 10). This outfit (d) is similar to outfit [Figure 11(c)] in style. The lower body region was not considered in those calculations, as it was not represented in the ‘atomic boy’ pattern data (Table 2).

Table 2 Estimations of upper BSANC for four garments: male gender, 8 yrs. old

<i>Data source</i>	<i>Outfit</i>	<i>DHM boy, 8 yrs.</i>
		<i>BSANC (dm²)</i>
DHM library	a	19.23
DHM library	b	21.81
DHM library	c	14.35
‘Atomic boy’	d	15.37

In this example, the relative error between the similar styles, the library generated garment pattern [Figure 11(c)] and the real-world ‘atomic boy’ pattern (d) is -7.1% .

4 Discussion

Calculation of the BSAC is highly dependent on the definition of the garment border lines (seam lines). Consequently, more detailed sleeve, skirt and trouser patterns are essential as well as additional neckline types in order to improve accuracy of BSANC simulation. This might be achieved using real-world patterns. For that reason, a preliminary procedure to adjust the UV map to a real-world pattern was employed. Additional studies however are required to confirm the real-world scale and aspect ratio. Also, further studies will need to include different sizes and patterns. The error generated from the BUFF dataset to DHM conversion has not been quantified in this instance as the assumption was made that it can be neglected. This assumption however will necessitate confirmation in another study.

Overall, we found only a small error of $-5\% < \varepsilon_1 < +3.5\%$ when comparing BUFF vs. DHM library determined BSANC. Similarly, the error between BSANC calculated from a library generated garment pattern [Figure 11(c)] and the equivalent real-world 'atomic boy' pattern (d) was deemed acceptable with $\varepsilon_2 = -7.1\%$. The slightly larger error ($\varepsilon_2 - \varepsilon_1 = -2.1\%$) when importing a garment pattern from design data (source: Adobe Illustrator), compared to a reference dataset can be assigned to a random error, as both patterns (datasets) required assumptions be made for modelling the seam lines, as argued above.

Given the complications arising from accessing a huge number of garment designs from a potentially large number of textile industry OEM or resellers, the practicality of an approach which is based on a DHM garment pattern library is obvious. If the quality of BSANC data generated using this method is good enough, such as partially validated in this study the significant economic benefits of the method make it the recommended future approach in measuring BSANC. Further validation and comparison with data from a traditional method have been previously published in Briceno et al. (2020).

The DHM and garment pattern library-based method of predicting BSANC has its application in the textile industry, in clothing sales, in selection of occupational health and safety related personal protective equipment (PPE) and in public health advice. Furthermore, the method is useful in dermatology and oncology research.

Given the small number of data used for validation in this study, further studies are mandated to confirm our conclusions.

5 Conclusions

We have presented a method to estimate body surface area not covered by clothing (BSANC). A clothing library for upper and lower body garment was proposed. We provided a comparative evaluation against the BUFF dataset bodies reproduced and BSANC by clothing was calculated for two outfits each from the library and the BUFF dataset. Using a real-world pattern, a preliminary procedure was used to adjust the UV map to a real-world garment pattern. This enables the comparison of BSANC by clothing for the virtual library generated garment against an equivalent real-world pattern. Errors within acceptable margins were found and explained.

It was shown that BSANC by clothing can be reliably determined from a DHM generated garment library, using a fully virtual DHM approach.

The outcomes of this study have implications for the garment industry and can assist with the efficient modelling of skin cancer risk in public health.

Acknowledgements

We thank our colleague, Simone Harrison (Atomic Playwear, Townsville/Australia) for provision of the 'atomic' pattern dataset, and Max Planck Institute for Intelligent Systems, Stuttgart/Germany for provision of the BUFF dataset.

References

- Bastioni, M., Re, S. and Misra, S. (2008) 'Ideas and methods for modelling 3D human figures: the principal algorithms used by MakeHuman and their implementation in a new approach to parametric modelling', in *Proceedings of the 1st Bangalore Annual Compute Conference. COMPUTE'08*, ACM, New York, Vol. 10, pp.1–6.
- Blender Foundation, *Blender* [online] <https://www.blender.org> (accessed August 2019).
- Blender Nation, *Magic UV Blender Tools* [online] <https://www.blendernation.com/2018/02/18/magic-uv-v5-0-released/> (accessed August 2019).
- Briceno, L. and Paul, G. (2018) 'MakeHuman: a review of the modelling framework', in *Proceedings of the 20th Congress of the International Ergonomics Association. IEA 2018, Advances in Intelligent Systems and Computing*, Springer, Vol. 822, pp.224–232.
- Briceno, L., Harrison, S. and Paul, G. (2018) 'Towards parametric modelling of skin cancer risk: estimation of body surface area covered by protective clothing using base mesh modelling', in *Proceedings of the 20th Congress of the International Ergonomics Association. IEA 2018, Advances in Intelligent Systems and Computing*, Springer, Vol. 822, pp.106–116.
- Briceno, L., Harrison, S., Heal C., Kimlin, M. and Paul, G. (2020) 'Parametric human modelling to determine body surface area covered by sun-protective clothing', *Ergonomics*, Vol. 63, No. 3, pp.293–306.
- Buys, K., Van Deun, D., De Laet, T. and Bruyninckx, H. (2011) 'On-line generation of customized human models based on camera measurements', in *International Symposium on Digital Human Modelling*, Lyon, France [online] <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.473.6120&rep=rep1&type=pdf> (accessed April 2019).
- Cignoni, P., Callieri, M., Corsini, M., Dellepiane, M., Ganovelli, F. and Ranzuglia, G. (2018) 'MeshLab: an open-source mesh processing tool', *Sixth Eurographics Italian Chapter Conference*, pp.129–136.
- Dove, T. (2019) 'Building patternmaking theory to better represent the female form', in Scataglini, S. and Paul, G. (Eds.): *DHM and Posturography*, Academic Press, London.
- Dura-Gil, J.V. et al. (2019) 'Clothing', in Scataglini, S. and Paul, G. (Eds.): *DHM and Posturography*, Academic Press, London.
- Gage, R., Leung, W., Stanley, J., Reeder, A., Barr, M., Chambers, T., Smith, M. and Signal, L. (2017) 'Clothing protection from ultraviolet radiation: a new method for assessment', *Photochemistry and Photobiology*, Vol. 93, No. 3, pp.1513–1518.
- Harrison, S.L. and Downs, N. (2015) 'Development of a reproducible rating system for sun protective clothing that incorporates body surface coverage', *World J. Eng. Tech.*, Vol. 3, No. 3, pp.208–214.
- Harrison, S.L., Buettner, P.G. and MacLennan, R. (2005) 'The North Queensland sun-safe clothing study: design and baseline results of a randomized trial to determine the effectiveness of sun-protective clothing in preventing melanocytic nevi', *Am. J. Epidemiol.*, Vol. 161, No. 6, pp.536–545.
- Harrison, S.L., Buettner, P.G., MacLennan R., Woosnam, J., Hutton, L. and Nowak, M. (2010) 'Sun-safe clothing helps to prevent the development of pigmented moles – results of a randomised control trial in young Australian children', *Ann. ACTM*, Vol. 11, pp.49–50.
- Poirson, E. and Delangle, M. (2013) 'Comparative analysis of human modelling tools', in *2nd International Digital Human Modelling Symposium*, Michigan, USA [online] http://mreed.umtri.umich.edu/DHM2013Proceedings/Individual_Papers/dhm2013_submission_24.pdf (accessed April 2019).
- Scataglini, S. et al. (2019) 'Design smart clothing using digital human models', in Scataglini, S. and Paul, G. (Eds.): *DHM and Posturography*, Academic Press, London.

- Shah, P. and Luximon, Y. (2019) 'Use of digital human modelling in product design', in Scataglini, S. and Paul, G. (Eds.): *DHM and Posturography*, Academic Press, London.
- Zhang, C., Pujades, S., Black, M.J. and Pons-Moll, G. (2017) 'Detailed, accurate, human shape estimation from clothed 3D scan sequences', *The IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, July, pp.4191–4200.

Notes

- 1 BUFF dataset: Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.