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Assessing the precision of 3D human model for forensic biomechanics application

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ABSTRACT

Three-dimensional (3D) human modeling is increasingly used in forensic biomechanics to reconstruct spatial relationships within incident scenes. A critical requirement is anthropometric fidelity. This study quantified the agreement between a customizable 3D human model and measured human anthropometry.

Eight key anthropometric dimensions, including stature, reach distances, limb lengths, and span, were collected from each participant and their corresponding stature-scaled virtual 3D models generated using the Human Generator add-on for Blender. Errors were expressed as mean absolute percentage error (MAPE) and mean signed percentage error (MPE), with two-sided 95% confidence intervals estimated by percentile bootstrap (10,000 resamples).

Agreement was high for stature (MAPE $<1\%$, MPE ≈ 0 for both sexes). Several segment and reach measures showed small errors around 5% or under. Two systematic discrepancies were identified. First, SPAN was consistently underestimated with a bias in males of approximately -8% and a MAPE of approximately 13.5%, and MPE of -3.9% and MAPE of 5.7% with females. Second, LOWER LEG was overestimated in males exclusively (MPE $\approx +8.7\%$ and MAPE $\approx 8.7\%$).

These findings highlight both the capability of such models for forensic applications while also highlighting some of the potential pitfalls. While certain measurements exhibit strong alignment, forensic practitioners must be aware of systematic errors when using stature-scaled models.

1. Introduction

In forensic biomechanics, incident reconstruction is often a useful tool to evaluate hypotheses about how events may have unfolded. Whether the goal is to assess visibility, body positioning, timing, or movement, the use of virtual human models is increasingly common in forensic settings. These reconstructions can rely on various methods, including photogrammetry, pose estimation, and more recently, Model-Based Image Matching (MBIM). In MBIM specifically, a 3D human model is matched to a participant's position in an image (or video frame), allowing for detailed spatial analysis of body posture and interactions within a scene.

A recurring challenge in this work is that investigators often have very limited anthropometric information about the individuals involved, commonly restricted to stature alone. Without full body measurements, forensic analysts must rely on assumptions, and often defaulting to population averages or standardized anthropometric databases. While this is a practical solution, it introduces an unknown amount of uncertainty.

To quantify this uncertainty, we compare a scalable 3D human model, generated using the Human Generator (HumGen3D) add-on for Blender with direct anthropometric measurements from human participants. This approach relies on the idea that an average-based model, adjusted for stature, may sufficiently resemble the participant for the purposes of reconstruction. We compare generated models to real measurements from a small sample population, with the aim of evaluating the validity of such tools in forensic reconstruction contexts where complete data is unavailable or, at least, impractical.

Outside of forensics, HumGen3D has been adopted as an asset source in peer-reviewed research across multiple fields. Studies have used it to create base avatars for perception experiments [1], to procedurally create controllable bodies within text-to-avatar pipelines [2] as well as to generate training data for multi-view reconstruction [3]. To our knowledge, however, there is no prior peer-reviewed anthropometric validation of this tool for forensic reconstruction. The present study addresses this gap by quantifying agreement between Human Generator models and measured human anthropometry under case-relevant dimensions.

In forensic biomechanics, accurately modeling human interactions with their environments is essential for reconstructing injury mechanisms and interpreting the physical context of events in both criminal and civil investigations. One critical aspect of such reconstructions is the

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Fig. 1. Example of Model-Based Image Matching using Human Generator's default proportions.

ability to depict persons of interest within a three-dimensional (3D) environment using anthropometrically accurate models that represent the individuals involved. This approach can be especially useful for quantifying the spatial relationships between individuals and their surroundings when using video analysis and 3D modeling to precisely position people within complex scenes especially when using methods such as Model-Based Image Matching [4] as showcased in the sample model shown in Fig. 1.

Three-dimensional human modeling, however, poses challenges related to anthropometric accuracy. Anthropometric data have been extensively investigated for various populations and applications [5,6], although anthropometric scaling factors obtained from these studies have limitations. Discrepancies in body proportions may introduce potential error when comparing the anthropometry of 3D models to actual individuals. In forensic applications, slight deviations between modeled and actual anthropometric dimensions may have implications for the analysis and subsequent conclusions. For example, differences in errors in arm length or forearm/upper arm ratio could affect the reach of an individual within the scene, a discrepancy which could end up impacting the interpretation of aspects like contact points, fall trajectories, or injury mechanisms [7].

Three-dimensional scene reconstruction has emerged as a powerful tool in forensic biomechanics, enabling the recreation of crime scenes with a high degree of spatial accuracy. This approach involves creating 3D virtual models of the environment, and individuals involved in an incident, based on detailed scene scans and basic anthropometric data. When accurately calibrated, these models facilitate precise evaluations of positions, angles, and distances, aiding investigators in understanding interactions within the crime scene [8,9]. However, discrepancies between the modeled anthropometric dimensions and real human measurements can introduce errors that may affect the integrity of the reconstruction and subsequent biomechanical analysis [10,11].

The objective of this study is to evaluate the accuracy of customizable 3D digital human models in representing real anthropometric measurements. By systematically comparing 3D models scaled to measured statures, we aim to assess the potential errors introduced and their implications for forensic applications. The findings will provide insights into the reliability of these models and guide best practices for their use in forensic biomechanics.

2. Materials and method

2.1. Participants

The study recruited male and female participants with a wide variety of characteristics. Focus was placed on acquiring anthropometric measurements for male and female participants consisting of a range of statures, including short (below 10th percentile), medium (average), and tall (above 90th percentile) stature categories as defined by a commonly employed U.S. dataset [5]. A total of 22 individuals were recruited into this study comprising 12 females and 10 males. The age range for participants comprised 18 to 70 years to capture typical adult anthropometry. Participant consent was obtained for all measurements, adhering to standard ethical protocols.

2.2. Measurements

The following eight anthropometric measurements were obtained from each participant and the corresponding 3D model to permit

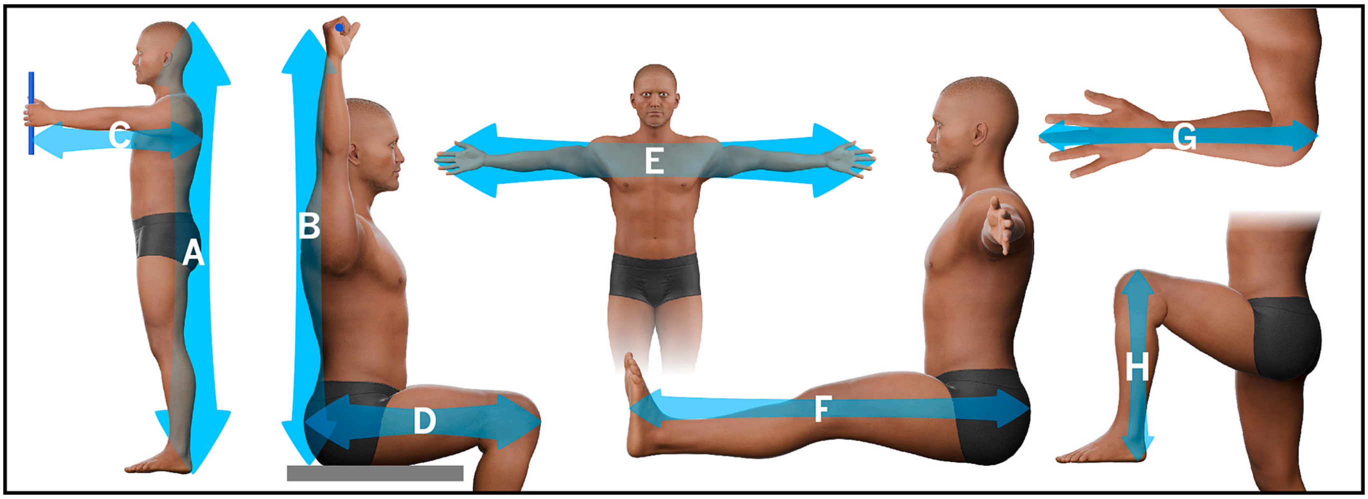


Fig. 2. Anthropometric measurements taken on both the participants and Virtual Model.

anthropometric comparisons. The measurements are shown in Fig. 2.

A. **Stature:** The vertical distance from the sole of the foot to the vertex of the cranium. The subject stood upright while an adjustable horizontal and level arm was lowered to make contact with the apex of the head. The arm position was secured, before the subject stepped aside, and a laser measuring tool was used to record the vertical distance between the floor and the arm at the point of contact.
B. **Vertical Reach:** The maximum vertical distance from the seated surface to a handle placed directly overhead. The subject sat upright on a rigid bench with their shoulder aligned beneath a vertically adjustable handle. They were instructed to reach upward and grasp the handle with a full grip while maintaining contact with the bench. The height from the seat to the supporting structure was measured using a laser tool and corrected for the offset between the structure and the handle's center.
C. **Horizontal Reach:** The maximum horizontal distance from the subject's back (in contact with a vertical wall) to a handle positioned anteriorly at shoulder height. The subject extended one arm forward to grasp the handle, curling the fingers around it. The distance from the wall to the vertical support structure carrying the handle was measured, and then adjusted to account for the distance between the structure and the handle's central axis.
D. **Thigh:** The horizontal distance from the posterior aspect of the buttock to the anterior surface of the knee. While seated on a rigid bench, the subject positioned themselves so that their buttocks made light contact with the backrest. With the knee bent at approximately 90°, a horizontal arm was placed across the anterior aspect of the knee to define the measurement point. The subject then stepped away, and the distance from the backrest to the horizontal arm was measured with the laser tool.
E. **Span:** The maximum horizontal distance between the tips of the middle fingers with both arms fully extended laterally. The subject extended both arms horizontally and pressed the fingertips against two opposing, adjustable plates. Once maximum span was achieved, the plates were fixed in position and the distance between them was measured with the laser tool.
F. **Full Leg:** The horizontal distance from the posterior aspect of the buttock to the posterior surface of the heel. The subject sat on the floor with one or both legs extended forward, parallel to a wall, with the foot in a neutral position. A backrest was placed in light contact with the buttock and heel. The subject then withdrew, and the distance between the two contact points was measured using the laser tool.
G. **Elbow-to-Fingertip:** The maximal distance from the posterior surface of the elbow to the tip of the middle finger, with the arm flexed at an angle greater than 90°. The subject rested their forearm in a pronated position on a linear metal guide, with the elbow against a fixed right-angle stop. The fingers were extended against an adjustable perpendicular plate. Once positioned, the plate was secured, the subject withdrew, and the measurement was taken using the laser tool.
H. **Lower Leg:** The vertical distance from the sole of the foot to the superior surface of the knee. The subject knelt on the floor with the shin vertical and the knee flexed to less than 90°. An adjustable horizontal bar was lowered until it made light contact with the top of the knee. Once the optimal shin angle and contact were established, the subject stepped away and the vertical distance from the floor to the contact point on the bar was measured with the laser tool.

All measurements were performed by the same trained researcher to ensure consistency and minimize inter-rater variability. Measurements were also performed using a custom structure composed of T-slotted aluminum tubing which acted as a person-sized caliper. A BOSCH Laser Measure (GLR225) was used for all linear measurements. The tool was selected for its precision (±1 mm), ease of use, and ability to provide consistent readings without direct contact. While more common in architectural and industrial applications, its use here was a practical decision based on the need for quick, repeatable measurements in controlled settings.

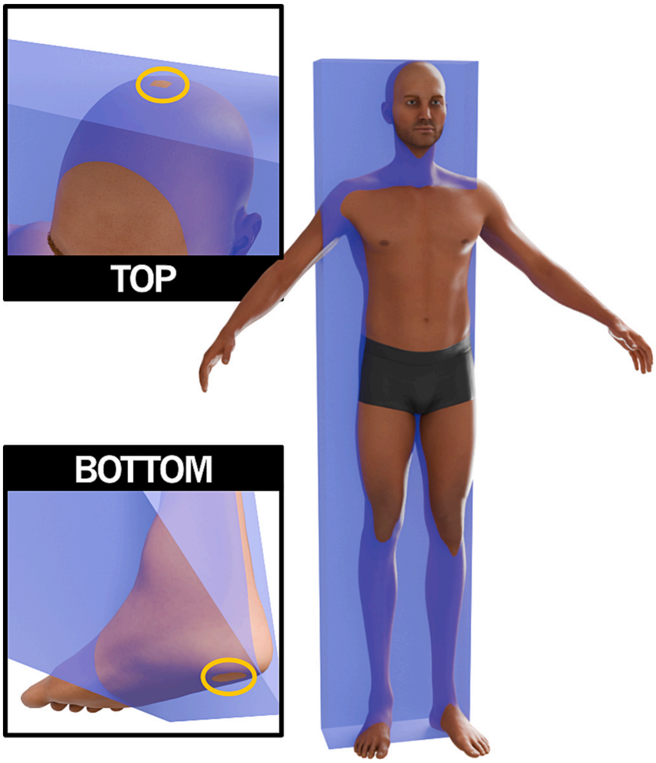


Fig. 3. Example of stature measurement taken from the Virtual Model. (exaggerated for ease of understanding).

For the Virtual Models, the subject was posed shown in Fig. 2, and the measurements were taken using cube objects aligned to encapsulate but not exceed the body in the measured dimension.

2.3. *Virtual model customization*

Each participant's measurements were replicated in a customizable 3D Virtual Model using the open-source *Human Generator (V4)*, an add-on for *Blender*, developed in the Netherlands. Human Generator allows users to generate realistic human models with customizable body features, poses, and textures.

As of this writing, Blender is available for free, and Human Generator is priced affordably for both corporations and individuals. Therefore, the tool was selected for its affordability, accessibility, and ease of integration into existing Blender workflows. HumGen3D was also selected as the preferred Virtual Model because it enables parameterized control of stature and body-shape attributes within a reproducible workflow and has documented use in recent research [1–3].

For each participant, the model was customized to match their specific anthropometric dimensions. Customization was restricted to scaling the model based on stature and sex with all other settings left as nominal, including body weight appearance parameters. The height input for the Virtual Model was rounded to the closest integer in centimeters since the add-on does not allow for decimal values.

2.4. *Comparison process*

Each Virtual Model was compared to the participant's **measured anthropometric dimensions**. The procedure was:

Table 1
Summary of participants used as part of this study.

		Short $<P_{10\%}$	Medium $P_{11\%} > X > P_{89\%}$	Tall $>P_{90\%}$
Male	*(units)*			
Number OF Subjects	*n*	3	4	3
Average Height	*cm*	164.7	175.3	190.5
Average Age	*years*	50.5	42.8	35.3
Mean Bodyweight	*kg*	76.4	100.2	85.6
Female				
Number of Subjects	*n*	3	6	3
Average Height	*cm*	152.9	163.9	175.5
Average Age	*years*	38.7	30.8	37.0
Mean Bodyweight	*kg*	56.9	59.9	76.7

Model creation from measured stature: For each participant, a HumGen3D Virtual Model was created based on the participant's **measured standing stature.** Since HumGen3D solves for stature based on all limbs proportion, the input has to be adjusted until the interface shows the desired value (rounded to the nearest whole centimeter, per the interface display). All other parameters remained at nominal values.

Standardized posing and scene setup. The Virtual Model was posed as shown in Fig. 2 to match each physical measurement configuration. For reaching measurements, a virtual handle object was included in the pose. Scene units were meters, with Blender's world origin placed on the ground plane beneath the model's feet and all scales applied to 1.

Virtual measurement capture. For each metric (A–H), an axis-aligned bounding object (cube) was positioned to overlap with the external body surface involved in the measurement axis, replicating the physical jig measurement (example in Fig. 3). The relevant dimension of the bounding object was recorded directly from the object's properties.

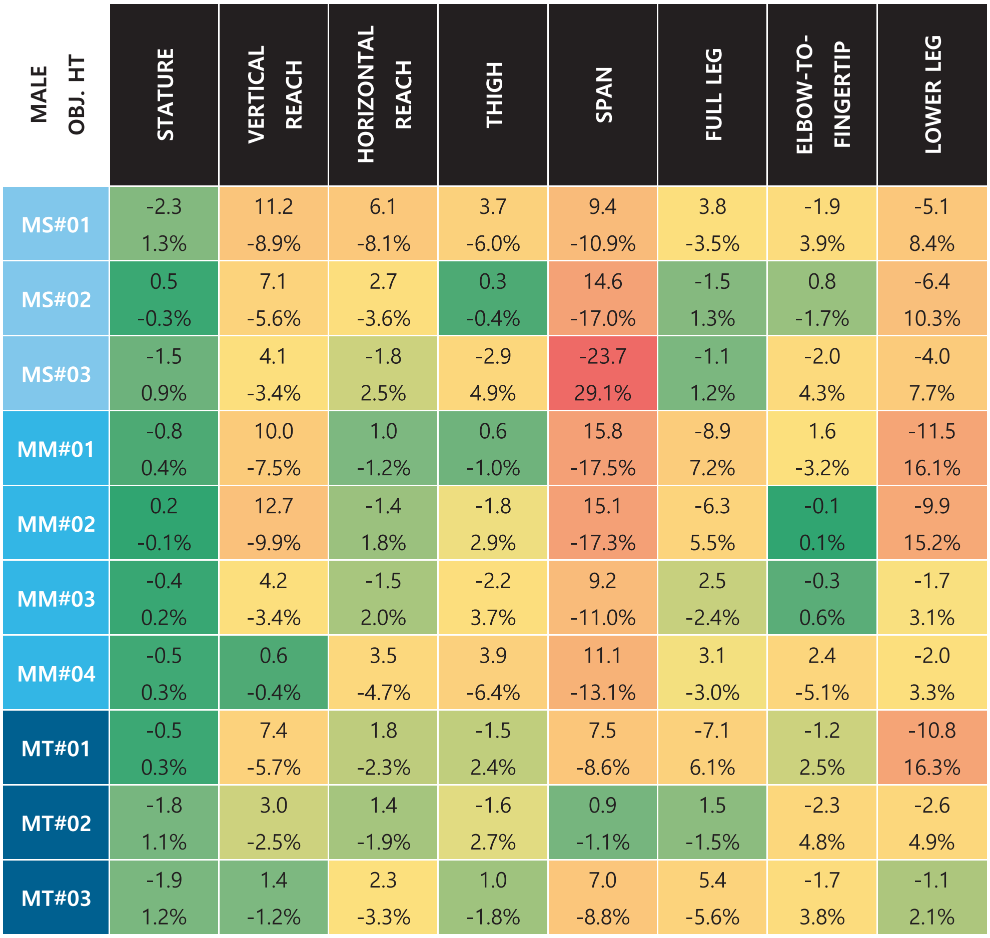
Error computation. For each participant and metric, the **model–to–measured difference** (Δ = Model − Human) and the **relative error magnitude** ($\Delta\%$) were computed as Δ divided by the participant's measured value.

This process yields paired observations (model vs. measured) for all eight anthropometric dimensions.

2.5. Statistical analysis

As the goal of this study is to evaluate the errors between Blender's generated Virtual Models and physical participants, a 95% confidence interval was calculated for each of the eight (8) categories of anthropometric measurements. The data were first sorted by sex (male and female) to focus on sex-specific evaluation. Bootstrapping was selected as a validated, frequently used and appropriate statistical method to account for the limited sample size [12]. It was performed as part of the individual analysis and consisted of 10,000 bootstrap samples for each

Table 2
Anthropometric measurements of male participants compared with Virtual Models scaled to stature. (Top result is the signed difference in millimeters, bottom result is the difference divided by the Virtual Model measurement).



MALE OBJ. HT	STATURE	VERTICAL REACH	HORIZONTAL REACH	THIGH	SPAN	FULL LEG	ELBOW-TO-FINGERTIP	LOWER LEG
MS#01	-2.3 1.3%	11.2 -8.9%	6.1 -8.1%	3.7 -6.0%	9.4 -10.9%	3.8 -3.5%	-1.9 3.9%	-5.1 8.4%
MS#02	0.5 -0.3%	7.1 -5.6%	2.7 -3.6%	0.3 -0.4%	14.6 -17.0%	-1.5 1.3%	0.8 -1.7%	-6.4 10.3%
MS#03	-1.5 0.9%	4.1 -3.4%	-1.8 2.5%	-2.9 4.9%	-23.7 29.1%	-1.1 1.2%	-2.0 4.3%	-4.0 7.7%
MM#01	-0.8 0.4%	10.0 -7.5%	1.0 -1.2%	0.6 -1.0%	15.8 -17.5%	-8.9 7.2%	1.6 -3.2%	-11.5 16.1%
MM#02	0.2 -0.1%	12.7 -9.9%	-1.4 1.8%	-1.8 2.9%	15.1 -17.3%	-6.3 5.5%	-0.1 0.1%	-9.9 15.2%
MM#03	-0.4 0.2%	4.2 -3.4%	-1.5 2.0%	-2.2 3.7%	9.2 -11.0%	2.5 -2.4%	-0.3 0.6%	-1.7 3.1%
MM#04	-0.5 0.3%	0.6 -0.4%	3.5 -4.7%	3.9 -6.4%	11.1 -13.1%	3.1 -3.0%	2.4 -5.1%	-2.0 3.3%
MT#01	-0.5 0.3%	7.4 -5.7%	1.8 -2.3%	-1.5 2.4%	7.5 -8.6%	-7.1 6.1%	-1.2 2.5%	-10.8 16.3%
MT#02	-1.8 1.1%	3.0 -2.5%	1.4 -1.9%	-1.6 2.7%	0.9 -1.1%	1.5 -1.5%	-2.3 4.8%	-2.6 4.9%
MT#03	-1.9 1.2%	1.4 -1.2%	2.3 -3.3%	1.0 -1.8%	7.0 -8.8%	5.4 -5.6%	-1.7 3.8%	-1.1 2.1%

Table 3

Anthropometric measurements of female participants compared with Virtual Models scaled to stature. (Top result is the signed difference in millimeters, bottom result is the difference divided by the Virtual Model measurement).

FEMALE OBJ. HT	STATURE	VERTICAL REACH	HORIZONTAL REACH	THIGH	SPAN	FULL LEG	ELBOW-TO-FINGERTIP	LOWER LEG
FS#01	-0.7 0.4%	1.4 -1.2%	-3.4 4.7%	0.3 -0.4%	8.9 -10.7%	4.0 -4.0%	-0.5 1.0%	3.2 -6.2%
FS#02	-0.4 0.2%	3.1 -2.5%	5.7 -7.9%	1.3 -2.1%	3.1 -3.6%	6.1 -6.0%	-1.0 2.1%	1.7 -3.2%
FS#03	0.5 -0.3%	0.9 -0.7%	8.8 -12.6%	4.3 -7.4%	3.6 -4.4%	9.2 -9.3%	-0.9 1.9%	-0.3 0.6%
FM#01	-1.1 0.7%	-1.4 1.2%	1.6 -2.4%	-1.7 3.1%	-3.8 4.7%	1.4 -1.5%	-3.8 8.4%	-1.0 1.9%
FM#02	-1.1 0.6%	0.7 -0.5%	-4.8 6.5%	-3.7 6.0%	2.7 -3.1%	1.1 -1.0%	-1.1 2.2%	1.2 -2.3%
FM#03	-0.4 0.2%	-3.5 2.9%	-3.9 5.6%	0.9 -1.5%	7.9 -9.8%	5.0 -5.1%	-1.7 3.7%	-0.1 0.1%
FM#04	-0.4 0.2%	-1.2 1.0%	-3.5 5.0%	-2.1 3.8%	-4.9 6.0%	0.0 0.0%	-4.1 9.0%	-0.2 0.3%
FM#05	-0.8 0.4%		3.3 -4.4%	2.6 -4.1%	7.2 -8.2%	8.8 -8.2%	1.0 -2.1%	3.3 -6.0%
FM#06	-0.2 0.1%	1.9 -1.6%	1.6 -2.4%	0.8 -1.4%	2.8 -3.6%	2.5 -2.7%	-2.5 5.6%	-1.8 3.7%
FT#01	-0.4 0.3%	2.9 -2.6%	4.0 -6.0%	-0.9 1.8%	7.3 -9.4%	1.3 -1.5%	-1.7 3.8%	-1.5 3.2%
FT#02	-0.2 0.1%	-3.0 2.6%	-3.2 4.9%	-0.7 1.3%	1.5 -1.9%	3.1 -3.4%	-2.2 5.0%	-0.1 0.2%
FT#03	-0.1 0.1%	1.3 -1.1%	1.9 -2.9%	0.9 -1.7%	2.2 -2.9%	0.6 -0.7%	-2.6 5.9%	-2.8 6.0%

anthropometric measurement. The mean error was calculated for each bootstrap sample and the collected bootstrap mean errors were used to compute a 95% confidence interval for each anthropometric measurement. The confidence interval was determined by identifying the 2.5 and 97.5 percentiles of the bootstrap distribution. The result is a dataset that comprises the range of systematic errors between the real and computer-generated anthropometric measurements. The statistical analysis was conducted in *Python* 3.11 on *Windows* using *Jupyter Notebook* (via the Anaconda Distribution). Key libraries used were *pandas* v2.2.3, *NumPy* v2.2.1 and *Matplotlib* v3.10.0.

Also, to verify that the virtual model generation is repeatable under identical inputs, we instantiated 10 male and 10 female models using the same parameters (sex preset and stature only). For each model, four measurements (STATURE, FULL LEG, THIGH, & SPAN) were re-measured using the same axis-aligned bounding-object method. Between-instantiation variability was summarized as standard deviation (SD) and error range. Inter-observer variability was not considered because all measurements were taken by the same individual.

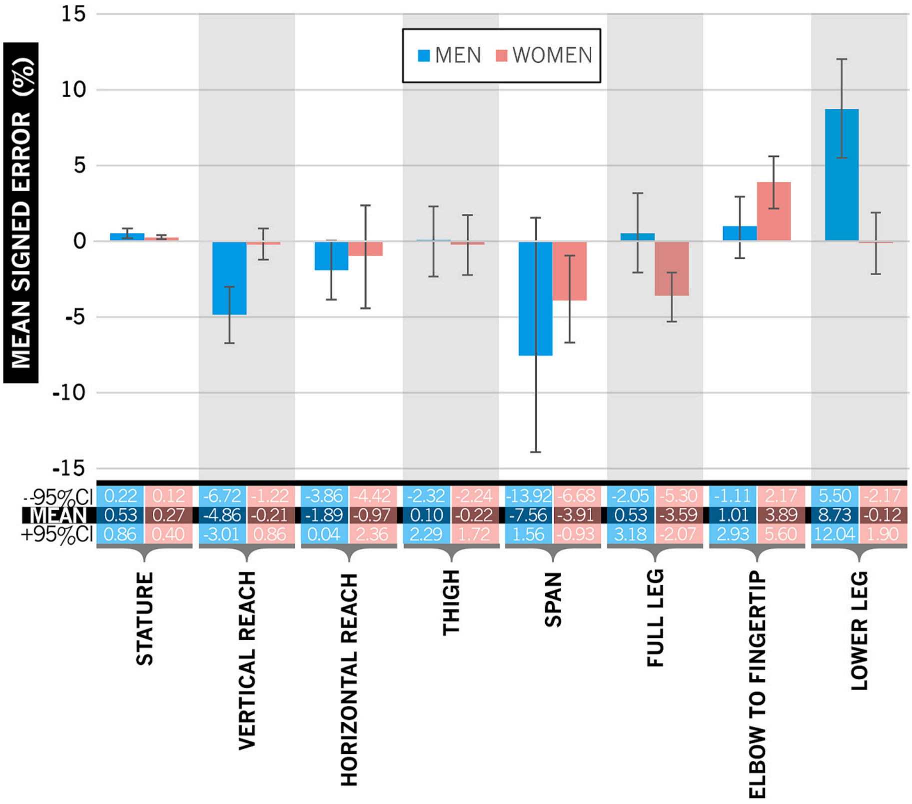
3. Results

The participant statures (as self-reported) ranged from 152 to 178 cm for females and 163 to 193 cm for males. Demographics of the recruited population are summarized in Table 1 for each subgroup.

For each subject and measurement, the mean signed difference (MPE), mean absolute percentage error (MAPE) and absolute error in millimeters (as reported in Tables 2 and 3) were computed. We report the MPE to characterize bias (positive = model overestimates; negative = model underestimates), the mean absolute percentage error (MAPE) to characterize magnitude of error irrespective of sign, and the absolute error (mm) to provide the corresponding magnitude in the original measurement units.

The measurements for each participant were compared to their equivalent in the Virtual Models. Table 2 and 3 shows the difference and relative error for each measurement. Participant FM#05 lacked the mobility to reach the handle used in the VERTICAL REACH posture. No result was, therefore, recorded for this subject for the VERTICAL REACH measure.

Results are reported relative to the measurements made on the physical participant. Therefore, a positive difference represents a greater



	STATURE		VERTICAL REACH		HORIZONTAL REACH		THIGH		SPAN		FULL LEG		ELBOW TO FINGERTIP		LOWER LEG	
-95%CI	0.22	0.12	-6.72	-1.22	-3.86	-4.42	-2.32	-2.24	-13.92	-6.68	-2.05	-5.30	-1.11	2.17	5.50	-2.17
MEAN	0.53	0.27	-4.86	-0.21	-1.89	-0.97	0.10	-0.22	-7.56	-3.91	0.53	-3.59	1.01	3.89	8.73	-0.12
+95%CI	0.86	0.40	-3.01	0.86	0.04	2.36	2.29	1.72	1.56	-0.93	3.18	-2.07	2.93	5.60	12.04	1.90

Fig. 4. Mean signed percentage error (MPE) values with 95% confidence interval.

length for the participant.

The results of the confidence interval computations are summarized in Figs. 4 and 5 for the MPE and MAPE respectively. Error bars shown represent the two-sided 95% confidence intervals for the mean estimated via percentile bootstrap (10,000 resamples). Between-instantiation reproducibility of stature (10 models/sex at fixed inputs) was under 1 mm (SD 0.27 mm, range −0.81 to +0.55 mm; women: SD 0.17 mm, range −0.41 to +0.28 mm).

4. Discussion

The results of this study indicate varying degrees of congruence between the Virtual Models produced using the Human Generator add-on in Blender and human anthropometric measurements. Overall, the findings reveal both close alignment in certain measurements and notable discrepancies in others, providing valuable insights into the limitations of this kind of modeling for forensic and biomechanical applications.

First, the difference in STATURE was minimal, with Mean Absolute Percentage Error (MAPE) below 1% for both males and females, and a Mean Signed Percentage Error (MPE) even closer to 0. It might be expected that there should be no difference in this measure between the participants and Virtual Models considering that stature is an input. However, the small discrepancy can be explained partially by the manner in which the algorithm used by the human generator model scales each segment to achieve a given height, and by the limit in height input resolution to the model (integer centimetres).

Additionally, an intra-observer repeatability check on a data subset showed sub-millimetric variability, indicating that model generation is repeatable under identical inputs. Together with the standardized bounding-object protocol, this supports the validity of the virtual measurement method provided the virtual pose matches the physical measurement posture; thus, the observed MPE/MAPE patterns likely reflect systematic proportional or pose differences rather than random generation noise.

The MAPE of the THIGH, FULL LEG, and ELBOW-TO-FINGERTIP length, were, on average, below 5%. This degree of agreement may be satisfactory considering the variability inherent in human anthropometry. Typical coefficients of variation for adult linear dimensions are reported on the order of ~3 to 9% [5].

Notably, VERTICAL REACH and HORIZONTAL REACH showed strong agreement between the virtual models and participants. For VERTICAL REACH, males exhibited a modest negative bias (MPE ≈ −4.9%, 95% CI roughly −6.7 to −3.0), whereas females were near zero on MPE; HORIZONTAL REACH biases were small for both sexes (MPE about −1% to −2%), consistent with the low-to-moderate MAPE observed. This result is encouraging given potential influences of mobility and task strategy on reach (e.g., incomplete elbow extension or compensatory trunk motion in some participants).

SPAN was the largest discrepancy and was consistently underestimated by the model. In males, MPE was approximately −7.6% with MAPE around 13.5%; in females, MPE was −3.9% with MAPE around 5.7%. This difference likely arises because, in the virtual pose, the arms were set at 90° abduction with the scapulae and clavicles held neutral, which constrains span to humeral length and shoulder breadth. In contrast, when participants maximized lateral reach, they likely also recruited shoulder-girdle motion (scapular upward/external rotation and clavicular elevation/retraction), which shifts the glenohumeral joint laterally and increases fingertip-to-fingertip distance [13,14]. In Blender/Human Generator these shoulder-girdle motions are not automatically coupled to humeral abduction and must be added explicitly, but were not included in the chosen pose. Incorporating shoulder-girdle kinematics when modeling lateral reach would be expected to reduce the underestimation of span in future use.

The LOWER LEG measurement was overestimated for males (MPE ≈ +8.7%, 95% CI ~ +5.5 to +12.0; MAPE ≈ 8.7%) but more accurate for females. This discrepancy may partially explain why the FULL LEG measurement showed a slight overestimation for males but an

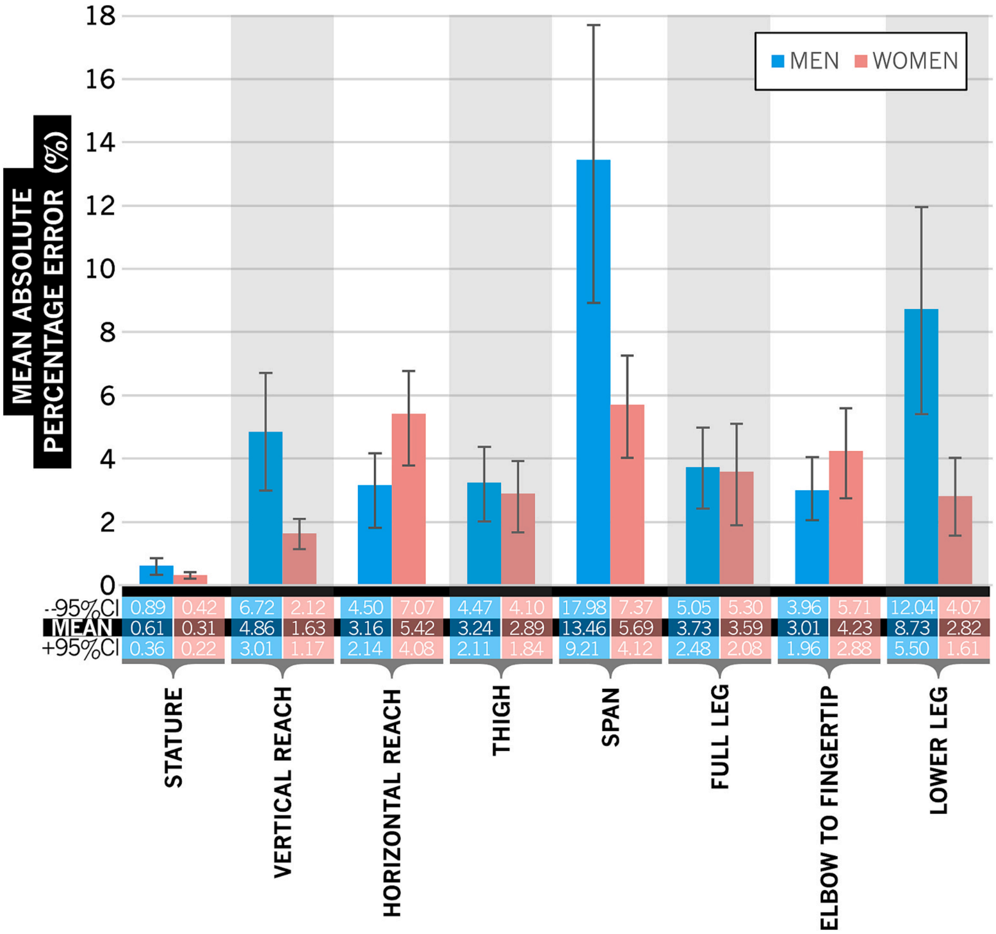


Fig. 5. Mean absolute percentage error (MAPE) values with 95% confidence interval.

underestimation for females. It is possible that the scaling algorithm used in the Virtual Model contributes to this pattern, where males' lower legs are disproportionately elongated, while females' full leg proportions are slightly reduced. Further refinement of segment scaling could help mitigate these inconsistencies and improve proportional accuracy across different body types.

Based on the statistical analysis performed, the model appears to be accurate to less than ±10% for the majority of the measurements taken. In fact, the confidence intervals for all measurements remained between −6.5% and +5.6% with the exception of SPAN and LOWER LEG for males. For the case of these two outliers, the higher degree of error should be taken into consideration when using such a model in a manner that depends on arm span or lower leg dimension. Given the modest sample size and non-random participant pool, these results should be interpreted as indicative rather than definitive, providing a foundation for broader validation studies.

As for limits to this study, models were generated using height-only scaling with nominal defaults; intra- and inter-observer repeatability was not assessed at this time, and the sample size was modest. Future work should aim to address these limits.

It should also be noted that differences in body weight between the tested population groups may have had an effect on the accuracy of digital anthropometric models. Body weight can be related to body morphology, posture, and soft tissue distribution, all of which impact measurement accuracy. For instance, although it was not considered directly for this study, individuals with higher bodyweight may exhibit differences in limb proportion and torso-to-limb ratios, potentially leading to greater discrepancies in Virtual Model predictions.

5. Conclusion

This study assessed the accuracy of 3D digital human models generated by Human Generator in representing study participants. By comparing Virtual Models scaled to measured stature with direct anthropometric measurements, we were able to characterize the difference between both.

The findings indicate that stature and many limb dimensions (such as thigh length and elbow-to-fingertip length) showed relatively small errors, suggesting that stature-based scaling can be effective for general body proportions. This suggests that while Virtual Models may not perfectly replicate every anthropometric detail, they are a valuable tool for forensic applications. These results provide an indication of the capabilities and limitations of digital human modeling tools for forensic biomechanics and serve as a foundation for future validation studies involving larger and more diverse populations.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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