OSSO vs SKEL: A Comparative Study of Skeletal Inference from 4D Body Scans

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Abstract

4D scanning techniques make it possible to accurately capture the posture, movement, and external shape of the human body. The resulting meshes generated with 4D scanners are highly detailed, with over 49,000 vertices and 99,000 faces, making them well-suited for analyzing surface deformations and dynamic motion. However, they are limited to describing only the outer surface of the body, and do not provide any information about internal anatomic structures, such as bones. And although internal structures can be reconstructed with MRI or CT scans [1], [2], these imaging devices are typically found in medical facilities and are significantly more expensive than 3D or 4D scanners.

As an alternative, automated systems that infer skeletal position based on the external shape of a body model provide an alternative way to add internal detail to 4D and 3D scan data. Currently, systems such as OSSO [4] and the more recent SKEL [3], both open-source tools developed by the Max Planck Institute, can be used to infer skeletal structure from a 3D body mesh, after it has been converted to the standard topology of a parametric model like SMPL [4], helping to create more accurate human models for different applications such as finite element simulations. Previous work has evaluated the use of OSSO to infer skeletal structure from SMPL-converted 4D scan data [5]. This study builds on those results by introducing and analyzing SKEL, which represents advancements in computational efficiency and biomechanical accuracy. The paper compares the skeletons generated by OSSO and SKEL to assess structural differences, fitting into the body models and inference quality.

Keywords: 4D Scanning · SKEL · OSSO · SMPL · Skeleton fitting.

1 Introduction

The detailed capture of the body surface using 3D and 4D (3D+time) scanning technologies has opened up a range of applications that benefit from accurate geometry of the human body. This level of fidelity enables the development of medical and sports products customized to individual morphology, the analysis of fit and comfort in motion, and the creation of anthropometric databases useful for fashion and sizing, biomechanics, computer graphics and computer vision.

In parallel, generating biomechanically accurate internal anatomical structures, such as skeletons, is equally crucial for multiple fields: medical and training applications, biomechanical analysis, exoskeleton design, orthotics/prosthetics, vehicular safety, and CG/VFX/VR pipelines. Accuracy matters in this regard, if the joints or skeleton are misaligned with respect to the skin, estimates of angles, moments and muscle loads are biased, compromising any analysis or machine learning system that relies on them [1], [2], [5].

Likewise, standardized body models such as SMPL (Skinned Multi-Person Linear Model)[4] or STAR (Sparse Trained Articulated Human Body Regressor) [6] are fundamental pieces of the current ecosystem. They establish a shared representation of the human body, defined by a common parameter space (pose θ and shape β), a fixed rig/mesh and a constant number of vertices and triangular faces. Such a configuration ensures that transformations, deformations and analysis are uniformly applicable between model instances. This uniformity is essential for comparative studies, to ensure that improvements or modifications can be transferred generally, and for machine learning systems such as OSSO and SKEL, which estimate anatomically plausible bones locations within the body to enable biomechanical applications [4].

With this motivation, this work compares the accuracy and fit in skeletal generation with SKEL and OSSO, evaluating their skin-bone coherence and their potential impact on biomechanical metrics and downstream applications.

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2 OSSO & SKEL

OSSO (Obtaining Skeletal Shape from Outside) predicts a subject's 3D skeletal shape directly from the external body surface, without requiring internal imaging of the target. To learn the skin–bone relationship, it leverages large-scale DXA (low-dose X-ray) data: STAR is fitted to the soft-tissue contours while a part-based skeletal model is fitted to the bone map, yielding paired interior–exterior examples. From these pairs, OSSO learns (i) a statistical shape space for bones (Principal Component Analysis, PCA) and (ii) a linear mapping from body- shape parameters (β) to bone-shape parameters (β_B). At test time, a body in an arbitrary pose is first canonicalized to a rest pose, the personalized skeleton is predicted, and the result is then re-posed under anatomical constraints to match the input pose [7].

SKEL (Skeletal Kinematics Enveloped by a Learned body model), by contrast, is a parametric body model that ties skin and skeleton to the same shape (β) and pose parameters (q). It starts from SMPL and re-rigs it with a biomechanical skeleton (BSM). To build SKEL, the authors create BioAMASS: they fit a biomechanical skeleton inside SMPL sequences from the AMASS [8] dataset using AddBiomechanics, producing a paired skin–bone corpus. With that paired skin-bone corpus the authors trained regressors from SMPL vertices to anatomical joint locations and bone rotations, and define a rig that models shoulder, spine and forearm more realistically (sliding scapula, constant curvature spine, pronation/supination). The result is a parametric "SMPL-like" model but with fewer degrees of freedom and more faithful kinematics, which places a correctly scaled and oriented skeleton within any SMPL mesh. Building on this, SKEL poses skin and bones in sync, and can upgrade existing datasets with biomechanical ground truth, and estimates internal joints with lower error than standard SMPL joints [3].

In summary, both methods learn a data-driven link between skin and skeleton, bridging vision/graphics and applied biomechanics, and both start from a parametric surface (SMPL/STAR). However, they differ in supervision, training data, and kinematics. SKEL is an integrated parametric model governed by biomechanical pose parameters and trained on moving bodies (AMASS + optimization in BioAMASS), producing a rig that moves skin and bones with the same pose vector. OSSO, in turn, is primarily a predictor of bone geometry from the exterior surface, trained on large-scale, real interior–exterior DXA–STAR pairs; it then re-poses by optimization and generalizes to arbitrary 3D body surfaces.

3 Methodology

Figure 1 overviews the pipeline of this paper. Starting from homologous surface meshes extracted from 4D scans, each mesh is converted to the SMPL topology. The resulting parametric bodies are then used to infer skeletal structures with OSSO and SKEL systems. Finally, the inferred skeletons are compare by fitting them back, both onto the parametric body and insde the original 4D meshes, to assess anatomical plausibility, collisions, and stability across different postures.

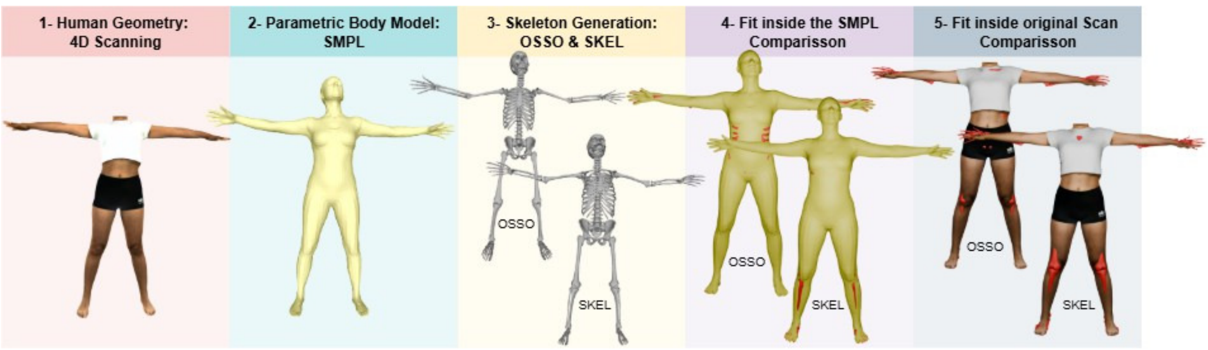


Fig. 1: Methodology.

3.1 4D Scan in various poses

Four 4D scans of a single adult subject (25 years, 160 cm, 52 kg) were captured using the Move4D scanner developed by IBV (Fig. 2). Two static reference poses A-pose and T-pose, and three dynamic sequences were taken: single-leg lift to the front, and single-leg lift to the back. Dynamic sequences were captured at 30 fps for 200 frames each.

From each dynamic sequence, representative frames were selected at the peak of motion (e.g., knee flexion or hip extension). The selected frames serve two purposes: (i) they represent a diversity of limb configurations and shoulder/forearm orientations that can be challenging for skin-to-skeleton inference, and (ii) they allow consistent comparison between the two skeleton models.

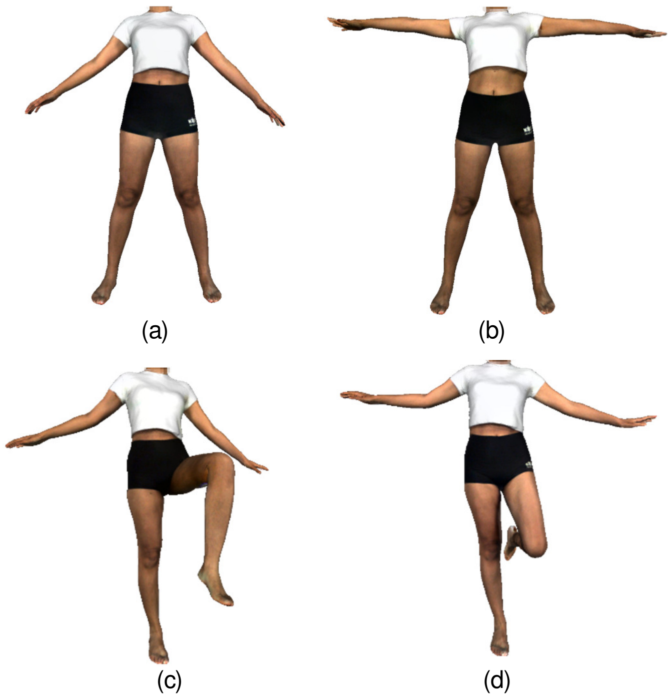


Fig. 2: Selected frames: a) A-Pose b) T-Pose c) Single-leg front d) Single-leg back

3.2 Parametric Model: SMPL retopology

Each 4D scan mesh was converted to the standard SMPL topology (6,890 vertices; 13,776 faces), using the programming environment developed by Shi [62] and the generate_batch.py function, included in the SMPL installation package [4]. This parametric representation of the subject normalizes mesh connectivity and exposes a common pose/shape parameterization required by both OSSO and SKEL to infered the skeleton within.

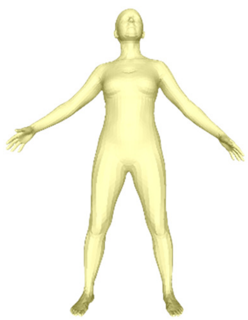


Fig. 3: Generated mesh, SMPL topology-Apose.

3.3 Skeleton Inference with OSSO

OSSO was executed on Ubuntu under WSL2 on Windows. A detailed system setup and package versions are documented in Annex 6. OSSO predicts 3D skeletal geometry from the external body surface. The SMPL mesh for each pose is provided as input; OSSO then regresses subject-specific bone geometry from the surface, and re-poses the bones under anatomical constraints to match the target frame resulting in an inferred skeleton.

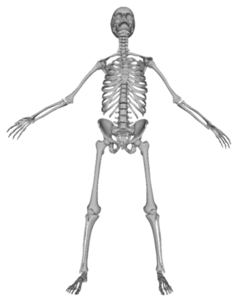


Fig. 4: OSSO: Inferred Skeleton model for A-Pose

3.4 Skeleton generation with SKEL

In contrast to OSSO, which use the geometry of the mesh directly and optimized a bone structure by proximity/anthropometric consistency. SKEL does not infer the skeleton from a static 3D mesh alone, it is designed to operate on SMPL model parameters, namely: poses (axis–angle joint rotations), betas (shape coefficients), and trans (global translation).

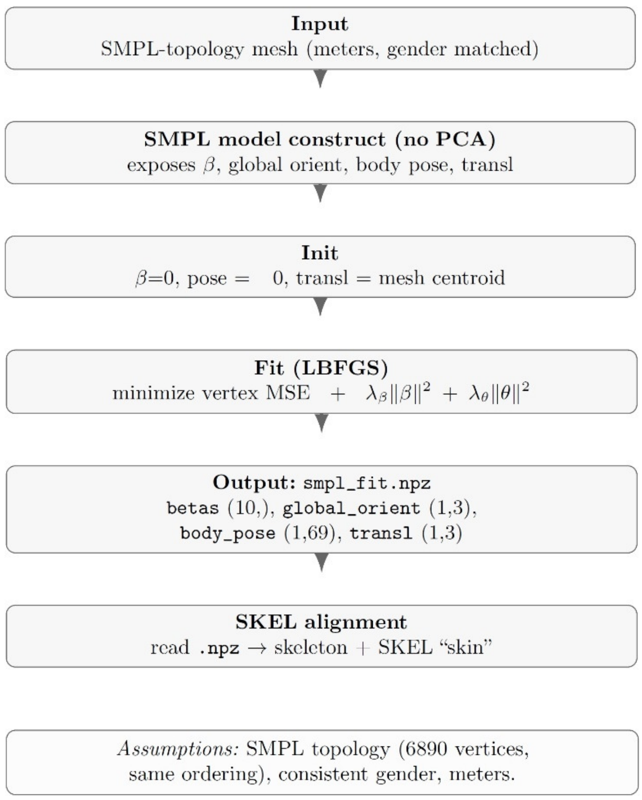


Fig. 5: Workflow to produce smpl_fit.npz from a SMPL-topology mesh and feed it to SKEL.

This is the way SKEL understand posture. Therefore, before running SKEL, a python code was created to extract the SMPL postural parameters from the SMPL-topology mesh and to package them into a single .npz file to then feed it to SKEL's alignment routine (Workflow in Fig. 5). An NPZ is a compact NumPy archive that stores multiple arrays (here: betas, global_orient, body_pose, transl) under named keys. Producing this file was necessary be- cause it provided SKEL exactly the inputs it expected, preserved the pose of the original scan with high fidelity, and made the process reproducible and lightweight to load in subsequent runs. Concretely, the script read the SMPL- topology surface (same vertex count and order as SMPL), built the SMPL model (with the appropriate gender), and optimized the unknown parameters (betas, global_orient, body_pose, transl) with LBFGS to minimize the mean-squared vertex error between SMPL and the target mesh. It then wrote the four arrays into smpl_fit.npz.

Once the NPZ had been generated, the SKEL code (align_to_SMPL_frame.py function) was executed with the supplied parameters to to place a correctly scaled, anatomically oriented skeleton inside the surface and to pose skin and bones in sync.

Fig. 6: SKEL: Generated skeleton in A-pose.

3.5 Skeleton-to-SMPL fit and comparison

For each selected frame, the posed skeletons produced by OSSO and SKEL were placed inside the SMPL body of the same frame. Both OSSO and SKEL output were overlaid on the corresponding SMPL mesh (Skeleton+SMPL).

The overlays were inspected in Blender to identify bone protrusions and local collisions (e.g., shoulder girdle, elbows, knees, hands/feet). Visual inspection emphasized whether bones remained enclosed by the skin and whether small gaps or penetrations appeared in challenging regions. For internal visibility, Gmsh was also used, where the body mesh is presented as a wireframe structure to see the skeleton through the surface.

3.6 Skeleton-to-scan fit and comparison

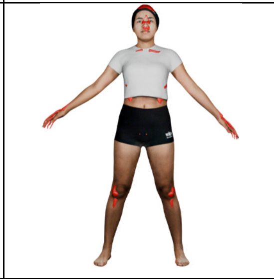
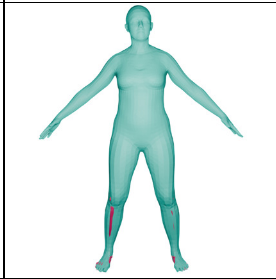
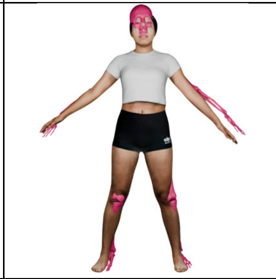
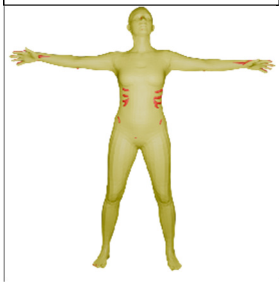
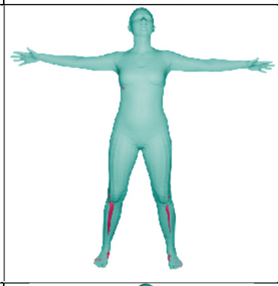
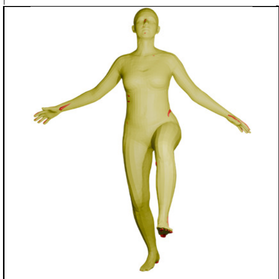
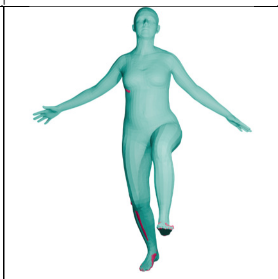
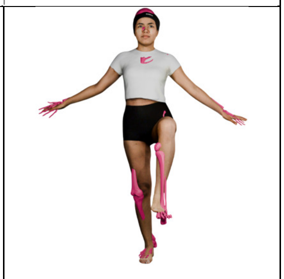
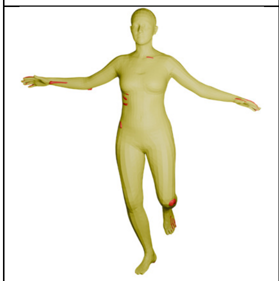
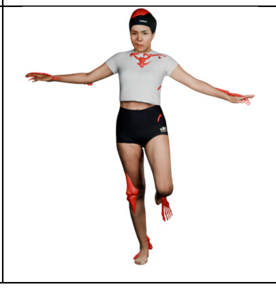
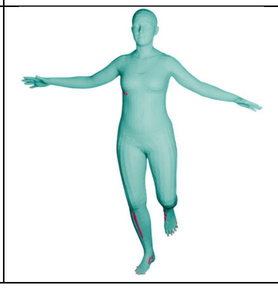
To evaluate placement within the measured geometry, the same skeletons were also mapped back to the original scan meshes. Blender was used to check for visible bone exposure at the surface, while Gmsh provided an interior view to confirm that long bones, pelvis, and rib cage remained properly contained.

4 Results and Discussion

Table 1 summarizes the results for each pose, skeletons were inspected inside SMPL and inside the original scan, using Blender for surface-level protrusions and to evaluate overall fit.

Given that SKEL also generated a "skin" mesh as a byproduct of its rig, and this skin has the same SMPL topology but was driven by SKEL's biomechanical kinematics (q) rather than by the original SMPL joint model, the SKEL model was fit inside this SMPL-like model in all instances. For each, SKEL's own Skin mesh is represented in light Blue and its skeleton in pink. For OSSO's results, the SMPL is presented in yellow, with OSSO skeleton in red inside the SMPL mesh. The software Gmsh for also used for internal visibility and bone placement with the SMPL meshes both for OSSO and SKEL.

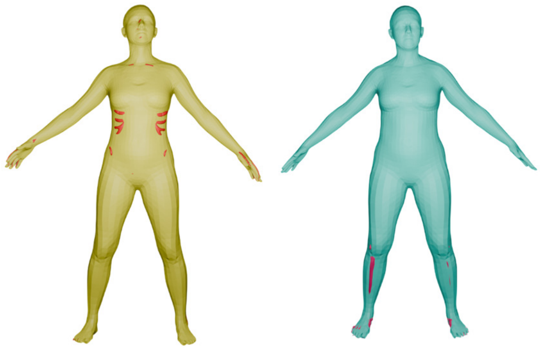
Table 1: OSSO & SKEL fitted in the SMPL meshes and Original Scans.

SMPL+OSSO	SMPL-skin+SKEL	Scan+OSSO	Scan+SKEL
			
			
			
			

4.1 Fitting Analysis: A-pose

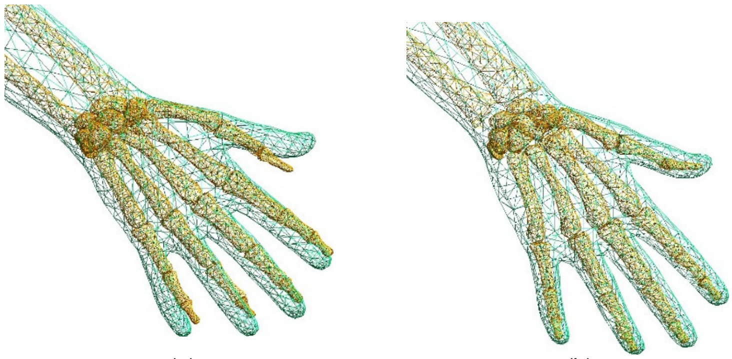
In the A-pose, both skeletons remained broadly plausible, yet the error differed by region. The skeleton obtained with OSSO aligns well within the SMPL surface (see Fig.7a) and long bones in the arms and legs showed a generally good fit. However, clear surface contacts were visible at the back of the cranium, both rib cages (lateral ribs/costal arches), the pelvis (anterior pelvis), and the heels of the feet (Fig. 9b). The hands exhibited the most obvious collisions, with several phalanges protruding through the skin (Fig. 9c).

SKEL, evaluated as SKEL+Skin (its own skin with SMPL topology driven by SKEL kinematics), showed a better fit with localized collisions: small contacts at the elbows, along the tibia, and at the feet (dorsum/heel). Outside these areas, the skeleton remained enclosed. A notable difference from OSSO was in the head, upper body, and hand region: SKEL achieved a remarkably accurate hand fit, with carpals/metacarpals and the finger rays contained within the palm (Fig. 13). The thorax, pelvis, and shoulder showed no major protrusions, consistent with SKEL's biomechanical rig.



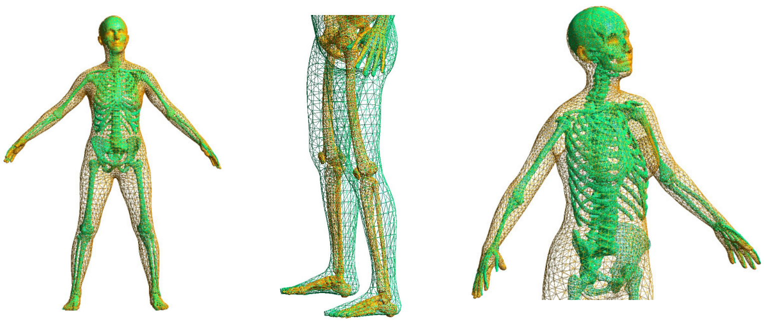
(a) (b)

Fig. 7: a) OSSO model fitted in A-Pose SMPL, b) SKEL model fitted in A-Pose SMPL-skin



(a) (b)

Fig. 8: a) Close-up of OSSO hand collisionsin A-pose, b)Close-up of SKEL hand fit in A-pose



(a) (b) (c)

Fig. 9: OSSO + SMPL A-Pose: a) OSSO merge with the SMPL mesh, b)Close- up of leg bones flexion and foot collisions, c)Close-up of hands collisions.

Internal alignment

Although in OSSO leg bones stayed inside the SMPL surface, a posture mismatch was noticeable, while the SMPL mesh showed slight knee flexion, the skeleton's bones remained straight (Fig. 9b). For the ribs, the thoracic vertebrae are slightly shifted to the left, leading to collisions (Fig. 14). The issues with the feet and heel primarily are caused mainly by the differences in knee flexion noted earlier.

For SKEL on the other hand, the internal view showed a well-centered rib cage and sternum with no widespread thoracic contact and a pelvis contained within the skin envelope (Fig. 10a).In addition, although it presents collisions with the left tibia, it shows a better response to flexion of the SMPL-Skin (Fig. 10b).

Fig. 10: SKEL + SMPL-skin A-Pose: a) OSSO merge with the SMPL mesh, b)Close-up of leg bones flexion and foot collisions.

Skeleton placement inside the original scan

When mapped back to the raw scan, the OSSO skeleton remained broadly plausible through the trunk, aided by the clothing layer that slightly thickened the surface. However, visible contacts persisted at high-curvature areas: the cranium/face, both hands (distal phalanges and around the wrist), knees/patella, ankles, and plantar sole. In side view, the knee posture mismatch was evident — the scan showed a small flexion while the OSSO long bones stayed almost straight, which explains the heel and plantar contacts. Overall, the intersections were numerous and spread across several regions.

The SKEL skeleton, overlaid on the same scan, stayed well contained through the torso (rib cage, sternum, and pelvis) and preserved the clean upper-limb alignment seen in SMPL space. Contacts were more localized: thin touches along the tibial crest and at the heel/foot dorsum, plus a pronounced cranial exposure (a cap-like region over the face/head).

4.2 Fitting Analysis: T-pose

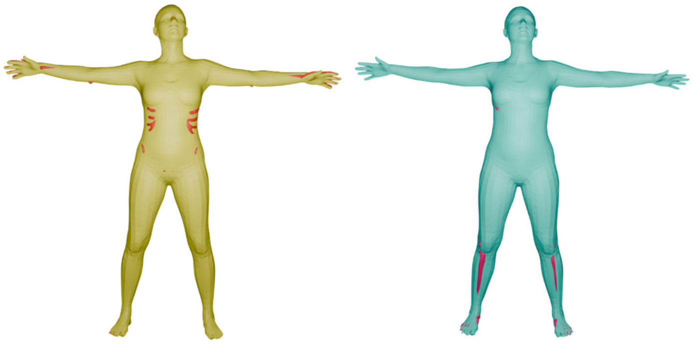
OSSO also produced a globally plausible placement inside the SMPL body in T-pose Fig.7a). Protrusions appeared again in the rib cage, pelvis, and and wrists/hands, but also elbows, and wrists/hands. Similarly, additional small contacts were visible along the forearms and around the ankles/forefoot.

SKEL, evaluated on its own skin, showed better overall enclosure at the shoulder girdle and trunk (Fig. 12b). Contacts were localized: small touches at the elbows, tibial exposure on each leg, and some heel and feet contacts. The axilla remained largely enclosed, and in general the skeleton stayed inside the surface.

One more time, for OSSO, the hands exhibited noticeable penetrations and minor wrist exposure (Fig. 13a). In contrast, SKEL achieved a cleaner hand fit (Fig. 13b): with finger bones contained within the palm volume, but with feet bones visibly bigger that the SMPL volume.

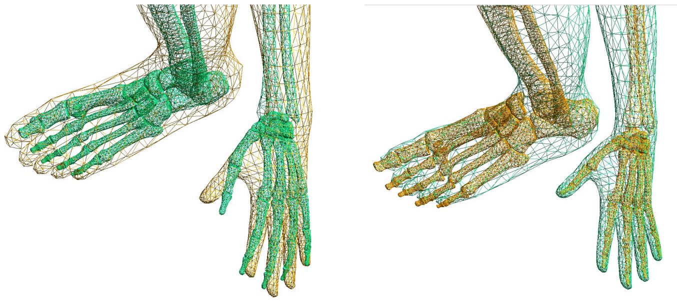
(a) (b)

Fig. 11: a) OSSO model fitted in A-Pose original Scan, b) SKEL model fitted in A-Pose original scan



(a) (b)

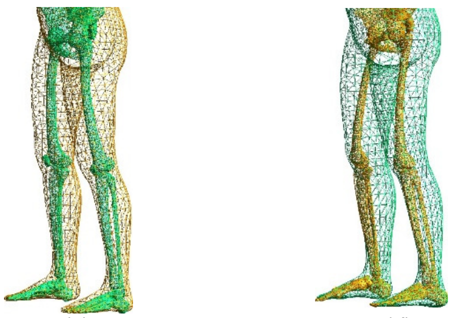
Fig. 12: a) OSSO model fitted in T-Pose SMPL, b) SKEL model fitted in A-Pose SMPL-skin



(a) (b)

Fig. 13: a) Close-up of OSSO hand and foot collisionsin T-pose, b) Close-up of SKEL hand and foot fit in A-pose

(a) (b)



(c) (d)

Fig. 14: a) OSSO merge with the SMPL mesh, b) SKEL merge with the SMPL- skin mesh Close-up, c) OSSO+SMPL, leg close-up flexion, d) SKEL+SMPL- skin, leg close-up flexion.

Although in OSSO leg bones remain inside the SMPL, a noticeable difference in posture is observed, while the SMPL model exhibits some knee flexion, the skeleton's bones remain straight (Fig. 9b). For the ribs, the thoracic vertebrae are slightly shifted to the left, leading to collisions (Fig. 14). The issues with the feet and heel primarily are caused mainly by the differences in knee flexion noted earlier.

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Skeleton placement inside the original scan

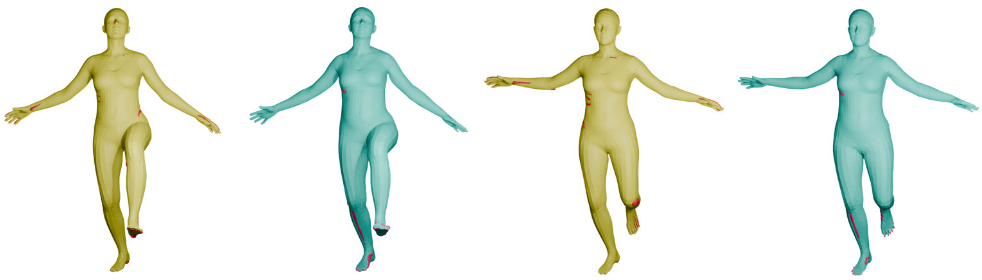
In T-pose, OSSO's knee posture matched the scan more closely than in A-pose, yet patella/ankle contacts persisted. The SKEL skeleton shows noticeably more protrusions than OSSO in the knee are while being align to the original scan, but less collision in general compare to the A-pose.

(a) (b)

Fig. 15: a) OSSO model fitted in T-Pose original Scan, b) SKEL model fitted in T-Pose original scan

4.3 Single-leg lift- Front & Back

Within the SMPL space. Across both hip-flexion (front) and hip-extension (back) frames, the two methods show good results, but SKEL+SMPL-skin showed a cleaner overall enclosure than OSSO+SMPL, especially in the hands and up- per limbs. Differences were not dramatic, yet consistent. SKEL's rig produced more realistic joint flexion (knee/ankle), which reduced thigh–knee misalignment seen with OSSO. OSSO again tended to keep the long bones slightly straighter, yielding shallow contacts at the patella, ankle/forefoot, and occasionally at the posterior pelvis in the back-lift. Recurrent SKEL hotspots were thin contacts along the the tibial and heel/dorsum touches. Other two systematic effects were visible: (i) the SKEL skin is a bit bulkier than the input SMPL, and (ii) SKEL feet bones appear larger than OSSO's, causing bigger toe/heel exposures in some frames.



(a) (b) (c) (d)

Fig. 16: a) OSSO merge with the SMPL-Leg front, b) SKEL merge with the SMPL-skin Leg front, c) OSSO merge with the SMPL-Leg back, b)SKEL merge with the SMPL-skin Leg back.

Skeleton placement inside the original scan

Back-projection to the original scan. When both skeletons were overlaid on the raw scans, fit quality dropped for both methods due to the pose approximation of the SMPL conversion. Errors concentrated in hands and feet, head and around the knee of the lifted leg.

(a) (b) (c) (d)

Fig. 17: a) OSSO merge with the Leg front Scan, b) SKEL merge with the Leg front Scan, c) OSSO merge with the Leg back Scan, b)SKEL merge with the Leg back Scan.

5 Conclusions

This study compared OSSO and SKEL for inferring internal skeletons from 4D scans by first retargeting meshes to SMPL and then evaluating each method in SMPL space and in the original scans. Both produced plausible results, but their goals and mechanisms differ and this shows up in their error modes.

While OSSO predicts the skeletal shape directly from the external body surface, learned from large-scale real interior–exterior data (DXA paired with STAR/SMPL). SKEL, by contrast, integrates skin and skeleton in one para- metric model, re-rigging SMPL with biomechanical constraints, so that joint locations and motions are more anatomical and biomechanically coherent.

In SMPL space, SKEL consistently yielded tighter enclosure and cleaner hand/upper-limb placement. Its collisions were mainly located at the elbow, anterior tibia and heels, while the torso and pelvis stayed well contained. Two systematic peculiarities persisted: SKEL's skin was slightly bulkier than the input SMPL or with small postural differences (very noticeable on the left arm of the Apose). And, SKEL foot bones were marginally larger, producing toe/heel exposure.

OSSO produced clean long-bone placement — notably, it avoided the tibial protrusion seen in SKEL, but at the expense of straighter bones. It showed small penetrations at typical surface–bone contact zones: lateral ribs, elbows, wrists, and ankles/forefoot. Hand alignment was less tight than SKEL's.

When skeletons were mapped back to the original scans, fit quality dropped for both. For the static poses, Apose and T-pose, OSSO shows a better overall fit to the Original scan. For single-leg poses, neither model achieved an acceptable scan-space fit, largely due to pose approximation during SMPL conversion and subject-specific shape that is not fully captured by the template.

Finally, this study provides a minimal, reproducible bridge to SKEL: a fitting script that estimates SMPL parameters (β, global orientation, body pose, translation) from a SMPL-topology mesh and packs them into a .npz. Feeding this file to SKEL's alignment step enabled reliable skeleton generation for arbitrary frames and a direct, repeatable comparison with OSSO.

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6 Annex 1: Configuration of OSSO system

Although the OSSO repository offers basic guidelines and installation require- ments, it falls short in providing a detailed setup process. To bridge this gap, more detailed instructions have been developed to facilitate the configuration and installation, and operation of OSSO.

Installation Guide for OSSO:

1. Activate the *Virtual machine platform* and the *Subsystem of Windows for Linux*.
2. Install Ubuntu 22.04 in the Subsystem of Windows for Linux using the following command in **PowerShell**:
   wsl –install -d Ubuntu-22.04
3. Install the required version of Python (3.8) and pip (20.2.4) using the following commands in **Ubuntu**:
   sudo add-apt-repository ppa:deadsnakes/ppa sudo apt update
   sudo apt install python3.8 pip install pip==20.2.4
   pip install --upgrade wheel pip sudo apt-get install python3.8-dev
4. Install the Python 3.8 virtual environment package:
   sudo apt install python3.8-venv
5. Clone the OSSO repository:
   git clone https://github.com/MarilynKeller/OSSO
6. Open OSSO, then create and activate the python virtual environment "osso_venv":
   cd OSSO
   python3.8 -m venv osso_venv source osso_venv/bin/activate
7. Install the libraries included in the file requirements.txt:
   pip install -r requirements.txt
8. Install Gloss-skeleton and the Perceiving Systems Mesh Package, open the folder of *mesh* and compile it using *make all*:
   git clone https://github.com/silviazuffi/gloss_skeleton.git
   git clone https://github.com/MPI-IS/mesh.git cd mesh
   make all
9. Return to OSSO and run:
   cd .. cd OSSO
   pip install . pip install tqdm
10. Download the following files:
    - https://star.is.tue.mpg.de/
    - https://osso.is.tue.mpg.de/index.html
11. Place the folders with the following order: **OSSO**
    - data
    - figures
    - gloss skeleton
      - gloss
      - models
      - osso
        - start_model
        - utils