Ref. Ares(2025)10398839 - 27/11/2025

D5.1 - VUM's schema editor and a set of programming tools for design and implementation of VHs v1

This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement number 101147722. The European Union is not liable for any use that may be made of the information contained in this document, which is merely representing the authors' view.

Project Acronym:	AccesS
Project Full Title:	Enhancing Accessibility and Sustainability in Smart Cities and Smart Buildings: The Universal Accessibility Suite Initiative
Grant Agreement:	101147722
Project Duration:	36 months (01/06/2024 – 31/05/2027)

DELIVERABLE 5.1 VUM's schema editor and a set of programming tools for design and implementation of VHs v1

Work Package:	WP5 Virtual User Modeling and Assistive Technologies for Accessibility
Task:	T5.1 Virtual User Models and VUM-based Virtual Humans
Document Status:	Final
File Name:	AccesS_D5.1_VUM's schema editor and a set of programming tools v1_FORTH
Due Date:	30.11.2025
Submission Date:	27.11.2025
Lead Beneficiary:	FORTH

Dissemination Level	
Public	☒
Sensitive	☐

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Version History

V	Author	Date	Brief Description
0.1	Emmanouil Zidianakis, FORTH	03.09.2025	Initial draft (ToC)
0.2	All authors, FORTH	10.10.2025	Draft version with initial content for all sections
0.4	All authors	30.10.2025	Updated based on partner's feedback
0.6	Emmanouil Zidianakis, FORTH	18.11.2025	Final draft for internal review
0.7	FRC, VAIMOO, FORTH	26.11.2025	Updated based on partners feedback
0.8	Emmanouil Zidianakis, FORTH	27.11.2025	Quality check and minor corrections
1.0	Dimosthenis Ioannidis, CERTH	27.11.2025	Available for submission to the EC

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Executive Summary

This work focuses on the implementation of a formal ontology for representing aging individuals and people with disabilities through the development of Virtual User Models (VUMs). Each VUM constitutes a semantic, data-driven representation of a human subject, integrating anthropometric parameters and human factors that influence digital and physical accessibility.

Building upon previous research (notably the VERITAS FP7 project) and enriched with new datasets from literature review, this work introduces the Virtual User Model Reference (VUMRef), a comprehensive framework encompassing visual, cognitive, auditory, and mobility metrics. VUMRef enables the accurate modeling of a wide spectrum of disabilities and functional limitations, allowing for realistic simulation of user interactions within the built environment.

To operationalize these models, this work delivers both a graphical user interface (GUI) editor for the digital authoring of VUMs and a toolchain for generating Virtual Humans (VHs), the 3D embodiments of VUMs in simulated environments. These VHs serve as test agents for assessing accessibility, usability, and safety during the design and evaluation stages of built environments.

In support of these tools, a dedicated REST API has been developed to operationalize and exchange VUM and VH data across the AccesS Suite. The API provides structured access to the semantic data of VUMs while also managing the efficient delivery of VH-related assets. The underlying semantic graph database further enhances these capabilities by enabling scalable data representation and robust interoperability with external systems and services.

Ultimately, this work contributes a foundational resource for the prediction and mitigation of accessibility challenges faced by individuals with disabilities aiming to advance universal accessibility in the built environment.

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List of Acronyms and Abbreviations

Term	Description
ADRef	AccesS Disabilities Reference
API	Application Programming Interface
CC	Character Creator
CRUD	Create, Read, Update, Delete
DfA	Design for All
DSST	Digit Symbol Substitution Test
GDPR	General Data Protection Regulation
GUI	Graphical User Interface
ICD	International Classification of Disease
MMSE	Mini-Mental State Examination
ROM	Range of Motion
SSO	Single Sign-On
VHs	Virtual Humans
VUMRef	Virtual User Model Reference
VUMs	Virtual User Models
WAIS-R	Wechsler Adult Intelligence Scale, Revised
WHO	World Health Organization
3MS	Modified Mini-Mental State Examination

1 Introduction

In recent years, significant progress has been made toward creating more inclusive and sustainable built environments. Guided by the Design for All approach, accessibility for persons with disabilities and older individuals has become a key priority, leading to the removal of architectural barriers and ensuring easier access to public spaces, buildings, and transportation.

Although major advances have been made in accessible infrastructure, the availability and adoption of digital tools that could meaningfully support persons with disabilities and older individuals remain limited. Technology offers significant opportunities to strengthen empowerment and inclusion. Such tools can enable professionals to anticipate and accommodate the needs of diverse user groups, ensuring that accessibility considerations become inherent to design rather than retrospective adaptations.

In this context, the present work introduces the Virtual User Model Reference (VUMRef), a semantic framework that supports the representation and simulation of virtual users with diverse disabilities. The VUMRef model encapsulates anthropometric, sensory, and kinesiological parameters that define the capabilities and limitations of individuals, enabling the creation of Virtual User Models (VUMs) and their embodiment as Virtual Humans (VHs) for use in 3D simulation environments. These simulations allow for the evaluation of accessibility, usability, and safety in both synthetic and reconstructed real-world environments, ultimately supporting the development of inclusive, adaptable, and equitable design solutions.

This work forms part of the European Union–funded project "Enhancing Accessibility and Sustainability in Smart Cities and Smart Buildings: The Universal Accessibility Suite Initiative" (AccesS) and contributes specifically to Task 5.1 *Virtual User Models and VUM-based Virtual Humans* (T5.1), which establishes the foundational framework for modeling and simulating human diversity as a mean to advance universal accessibility within built environments.

1.1 Scope and objectives of the deliverable

The scope of this deliverable is to present the conceptual framework, implementation methodology, and technical outcomes of Task 5.1, which focuses on the formal representation of aging individuals and people with disabilities through VUMs. This deliverable *D5.1 VUM's schema editor and a set of programming tools for design and implementation of VHs v1* defines the VUMRef, a comprehensive ontology integrating anthropometric data, sensory and motor performance parameters, and human factors that influence accessibility in both digital and physical environments.

The primary objectives of this work are to:

- Establish a formal semantic model capable of representing a wide range of physical, sensory, and cognitive characteristics;
- Develop a Graphical User Interface (GUI) schema editor and supporting programming tools for the design, implementation, and management of VUMs and VHs;
- Generate VHs as 3D embodiments of VUMs, whose behavior and interactions within 3D simulation environments reflect the characteristics and limitations specified within each VUM.

The deliverable provides the foundation for subsequent activities in Task *5.2 3D Simulation environments*, where the VUM-based VHs will be integrated into 3D simulation environments to assess accessibility, usability, and safety in realistic scenarios. In this way, the deliverable contributes directly to the project's overarching objective of promoting Design for All principles throughout the design and evaluation process of built environments.

1.2 Structure of the deliverable

The present document is organised to provide both the conceptual background and the technical details necessary to understand the design and implementation of the VUMRef and its associated tools for design and implementation of VHs. Following this introductory chapter, this report includes the following chapters:

- **Chapter 2** presents the background and core concepts related to user modelling, including existing approaches, standards, and theoretical foundations relevant to virtual user representation.
- **Chapter 3** introduces the VUMRef, detailing its structured semantic foundation, and its role in supporting the digital representation of virtual users.
- **Chapter 4** presents the Disabilities Reference Structure, offering an overview of the categorisation and modelling of general types of disabilities and their effects of a at different stages of severity.
- **Chapter 5** provides sample user profiles, illustrating how the VUMRef can be instantiated to represent diverse users and abilities.
- **Chapter 6** describes the overall toolchain supporting the implementation of Virtual Humans (VHs), highlighting the workflow from VUM definition to VH generation.
- **Chapter 7** introduces the VUMs GUI Editor, describing its functionalities for creating, managing, and editing VUM instances.
- **Chapter 8** presents the VHs GUI Editor, focusing on the tools that enable the design, visualization, and configuration of Virtual Humans derived from VUMs.
- **Chapter 9** concludes the document by summarising the main outcomes and remarks of this report.

Finally, Annex A and B introduce two indicatives user profile samples.

1.3 Relation to Other Tasks and Deliverables

Task 5.1 builds upon data from previous research (notably the VERITAS FP7 project) and findings from Work Package 1: *Design and Integration of the AccesS Framework: Setting the Foundations for a Smart and Accessible Built Environment* (WP1) and Work Package 2: *Social Inclusion and User-Centered Design Approach* (WP2), which provide the foundational anthropometric, cognitive, and behavioural datasets used to initialize and refine the Virtual User Models (VUMs). Knowledge and insights derived from these earlier activities ensure that the models accurately represent diverse user groups, including aging individuals and people with disabilities.

A REST API developed within Task 5.1 supports integration with other components of the AccesS Suite, enabling consistent data interoperability across the AccesS architecture. In detail, the work in Task 5.2 *3D Simulation environments* (T5.2), uses the REST API to serve as a critical translation layer for the assessment of the generated VUM-based Virtual Humans. These 3D simulation environments, which may represent either synthetic or reconstructed real-world pilot sites, provide the context in which VUM-based VHs are evaluated in terms of accessibility, usability, and safety and will be deployed in AccesS pilot sites during demonstration activities (WP10-WP12).

2 Background and Concept of User Modeling

2.1 User Models

User models can be viewed as an individual user's representation, encompassing needs, preferences, and physical, cognitive, and behavioural characteristics [1]. Early use of the term ’user model’ as an area of interest in computer science can be traced back to the 1970s-1990s. E.A. Rich et al [2] use that term to refer to an aggregation of user preferences, tendencies and limitations, while examining an interactive book recommendation system named Grundy that infers information and updates the model of the user according to the feedback received. S.K. Card et al [3] present the Keystroke-Level Model, a system that analyzes the performance of experts on specifically defined tasks that include system interaction. It calculates the estimated performance expected in similar tasks and highlights its value as a usability assessment tool for designers.

In 1985, Kieras & Polson [4] proposed a paradigm for the analysis of user complexity in interactive systems, utilizing three distinct formal models for any given user performing a task: a) the user’s job-task representation, detailing a person’s understanding of the task and their perception of the method and timing required to achieve it; b) the user’s model of a device, describing the user’s understanding of the device (device in this context referring to the complete system of hardware and software) they are using; and c) the formal model of the device which outlines the actual behavior of the system. The authors also highlight the importance of using simulations to realize the full benefit of formally analyzing user complexity with this method.

Robert B. Allen [5] examines the efficiency of utilizing a user model as a method of personalized information filtering, specifically in the context of news article recommendations, and adopts the functional definition of the term ’user model’ as ”the knowledge and inference mechanism which differentiates the interaction across individuals”. This also marks one of the earliest comprehensive attempts to raise important questions about user models in general, such as evaluation techniques, and limitations, with the author continuing their work a few years later, outlining different categories of user models and examining them in the context of different fields of Human-Computer Interaction (HCI) [6].

In more recent years, M.J. Pazzani & D. Billsus [7] focused on user models resulting from machine learning as an integral part of content-based recommendation systems, and analyzed different learning algorithms to extrapolate a user’s preferences. In the same vein, L. Zheng, V. Noroozi & P.S. Yu [8] presented DeepCoNN, a deep learning analysis tool consisting of two parallel neural networks, one of which focuses on learning user behaviors, by using natural language processing techniques to extrapolate data from their reviews for an item, and the other learns item properties based on the reviews written about them.

Regarding user modeling in the context of simulating physical interactions, E. Todorov, T. Erez & Y. Tassa [9] developed the MuJoCo physics engine, which allows for model-based definition of simulation environments for the purposes of robotics, biomechanics and graphics. The models support multiple formats, including XML, which are then converted into the human readable and editable MuJoCo format.

Finally, particular note must be made of the EU VUMS Cluster of projects [1][11]. The EU VUMS Cluster includes four projects, VERITAS, GUIDE, MyUI, and VICON, with a shared philosophy. While all four projects operate using their own internal user model structure, they also offer two-way compatibility with the VUMS Exchange Format, a common user model that includes metrics that codify the capabilities of a represented user, including auditory, visual, speech, cognitive, and mobility metrics. More specific, VERITAS is used to evaluate automobile designs, GUIDE simulates user interactions with computer interfaces, MyUI utilizes its user model in order to tailor an interface to the needs it predicts for that person, and VICON assesses the accessibility of virtual prototypes. While each system requires different areas and granularity of information, conformity to a common standard offers a valuable opportunity for larger-scale aggregations of people, translating to a larger coverage of disorders and disabilities. The VUMS Exchange Format is represented as an XML file, allowing for human and machine-readable user profiles and facilitating a more effective communication of information between systems and their users. It is worth noting that examining the work of VICON and VERITAS in detail, it can be concluded that declarative user models can yield significant results in the simulation of interactions with physical products and examining their usability during the design phase.

2.2 Terminology

In order to avoid confusion or ambiguity, the following terms are defined as employed in the context of VUMRef [11].

- **User Model**: An (abstract) user model is a set of user characteristics required to describe a user. The characteristics are represented by variables. The user model is established by the declaration of these variables. It is formally described in a machine and human readable format. An instantiation of the user model is a user profile.
- **User Profile**: A user profile is an instantiation of a user model representing either a specific real user or a representative group of real users. It is an instantiation of an (abstract) user model formally described in a machine and human readable format.
- **Virtual User**: A virtual user is a representation of a user based on a user profile.

3 Virtual User Model Reference

The Virtual User Model Reference (VUMRef) is centered around four key aspects; robustness, scalability, interoperability, and ease of use. The first step towards designing the model reference, was to finalize the main accessibility types to focus on, in accordance with the user requirements documented in the context of the AccesS project. The areas identified are the following:

- **General Information:** Generic information about an individual. Example variables include: age, height, sex.
- **Visual Information**: Detailed information about the visual characteristics of an individual. Example variables include: visual acuity, contrast sensitivity, colorblindness.
- **Mobility Information**: Information related to the physical status of an individual, including parameters related to strength, flexibility, and potential kinesiological limitations. Example variables include: push strength, elbow flexibility, step length.
- **Auditory Information**: Detailed information about the auditory characteristics of an individual. Example variables include: hearing loss.
- **Cognitive Information**: Information related to the cognitive capabilities, decision-making skills and mental characteristics of an individual.

Thus, the VUMRef model comprises general, visual, mobility, auditory and cognitive information. The selection was based on the level of sophistication needed both for the formalization of the relevant information into a user model, and the simulation in a way that would provide valid conclusions about the accessibility within built environments.

The following subsections present a detailed outline of VUMRef in a Neo4j relational graph database, where a person is described by a knowledge graph with a *Person* node as the root. The properties of the *Person* node of each user profile are presented in Table 1.

Table 1. Person node properties

Property	Value type	Notes
name	string	The first name of a person. Serves the purpose of identification, along with the ’surname’ field
surname	string	The last name of a person. Serves the purpose of identification, along with the ’name’ field

Currently the model reference is built upon four distinct types of nodes: *Person*, *Information*, *Structure*, and *Metric*. These types are mutually exclusive and mandatory, meaning each node in the model belongs to exactly one of these categories. Figure 1 illustrates that structured representation of a VUM, where each node type contributes a specific layer of information. The *Person* node serves as the unique root of the model, anchoring all information related to the user. Connected to it, *Information* nodes capture distinct fields of descriptive data, which are further organised through *Structure* nodes that provide hierarchical or conceptual grouping without introducing anthropometric values. Quantitative aspects of the user profile are expressed through *Metric* nodes, each encapsulating measurable properties relevant to a particular domain. Together, these interconnected nodes form a flexible and extensible graph that supports detailed, semantically rich user modelling.

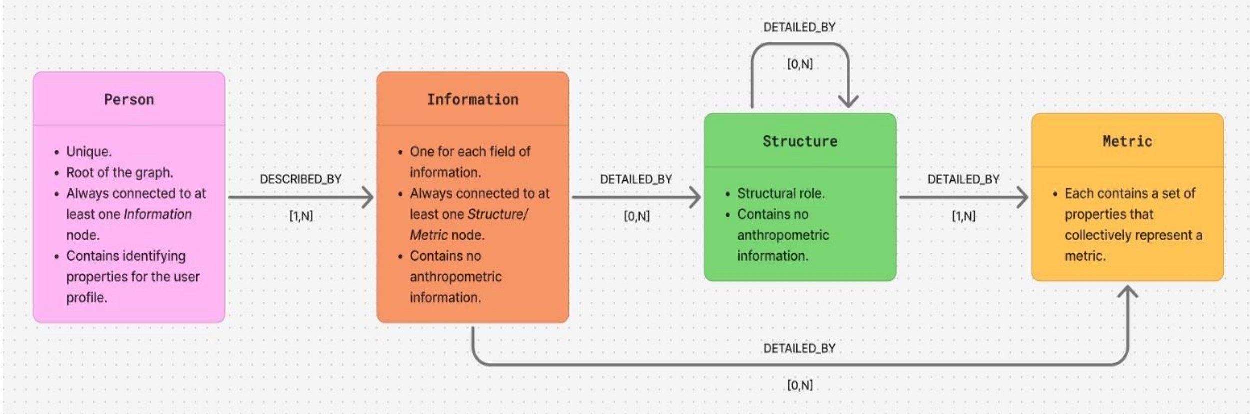

Figure 1. VUMRef Model Structure

Hereafter all nodes included in the following figures are coloured according to their type: pink for *Person* nodes, orange for *Information* nodes, green for *Structure* nodes, yellow for *Metric* nodes.

In the current version of the model, Metric nodes follow one of two possible structures depending on the value type of each metric, being either an arithmetic value within specified bounds, or a choice between enumerated options (see Table 2 and Table 3).

Table 2. Arithmetic value node structure

Property	Value type	Example metric for ”Height”
value	int or float	175
unit of measurement	string	centimeters
minimum	int or float	80
maximum	int or float	250
desc	string	Free text

Table 3. Enumerated value node structure

Property	Value type	Example metric for ”Sex”
value	string	”Undisclosed”
unit of measurement	string	”unitless”
options	list of strings	[”Male”, ”Female”, ”Undisclosed”]
desc	string	Free text

As presented in the tables above, each node includes a description (*desc*) property that has no default or expected value. This is a free text field relating to each metric, with the purpose of being filled by the creator of a user profile to record additional information, or notes that they deem helpful to other potential groups interested in that specific user profile (e.g., an expert creating a user profile for a person with myopia, adds a note to inform other interested parties that the measurements for distance visual acuity were obtained through a clinical examination using the Snellen chart [12]). The inclusion of this field was deemed beneficial in encouraging knowledge exchange between users of all backgrounds, as a direct and simple way to include information that cannot be easily formalized or predicted, but could nonetheless add context to the values provided.

Figure 2 presents a visualization of the relationships between the *Person* node and the *Information* nodes of each area covered by the model's current version.

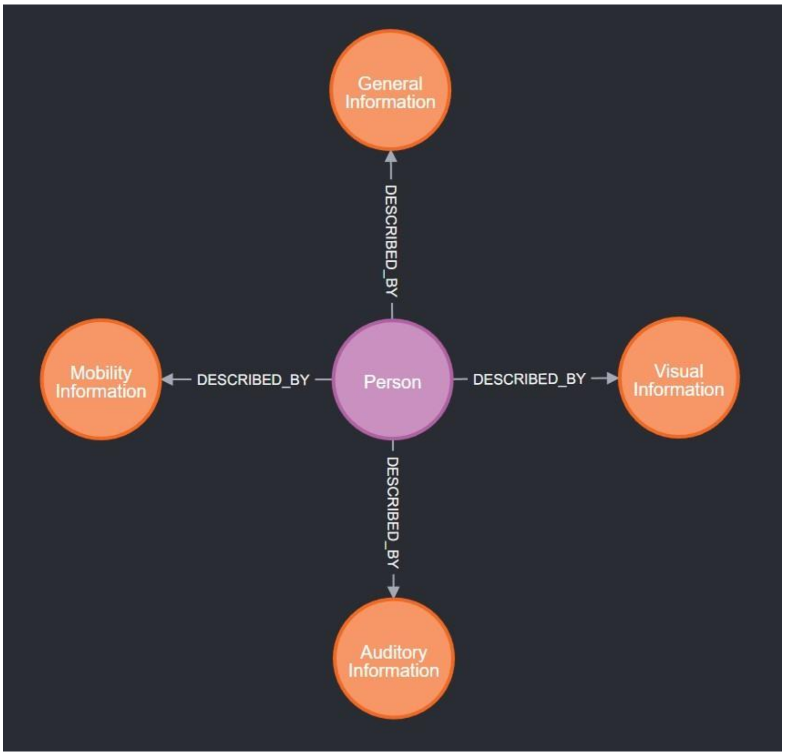

Figure 2. Person node relationships

The four areas of information are presented in the following chapters, along with details about the various metrics they cover.

3.1 General Information

General information includes demographic information that have significant impact on various other metrics, and cannot be reliably extrapolated from the body of a user profile, including age, sex, height and weight. Each of those metrics is represented by a single *Metric* node, as presented in Figure 3, and details for each are included in Table 4.

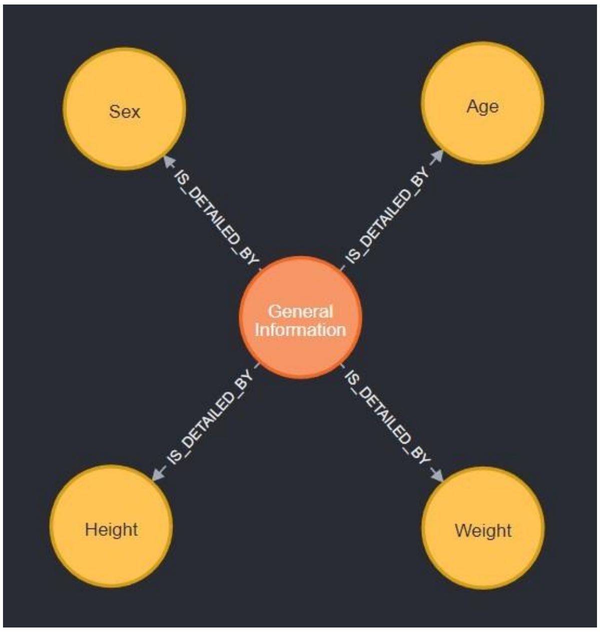

Figure 3. General Information

Table 4. General Information metrics

Property	Unit of measurement	Notes
Sex	unitless	Enumerated value ["Male", "Female", "Undisclosed"]
Age	years	
Height	centimetres	
Weight	kilograms	

3.2 Visual Information

Visual Information refers to all variables that revolve around a person's vision. VUMRef includes metrics for a person's near and distance visual acuity, contrast sensitivity, and peripheral vision range, with each of those variables recorded separately for each eye. The model also includes information about a person's colour vision health (or deficiency). All nodes relating to visual perception are structured as presented in Figure 4.

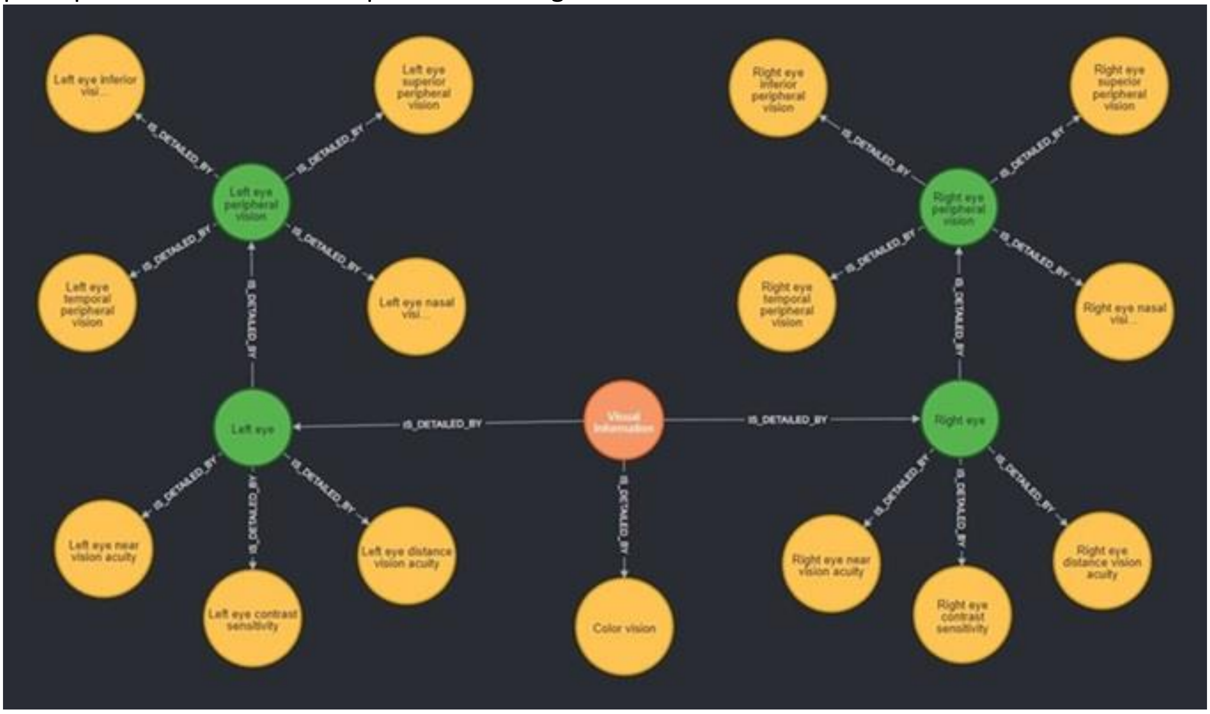

Figure 4. Visual Information

As noted in Figure 4, the nodes annotated as "Left/Right Eye" and "Left/Right eye peripheral vision" are *Structure* nodes, thus they contain no further information that could be used. Details and notes for all metrics pertaining to visual perception are presented in Table 5. Although most metrics are kept separately for each eye, they are identical in structure. In those cases, the node is marked in Table 5 as "Left/Right..." to avoid repetition.

Table 5. Visual Information metrics

Property	Units	Notes
Color Vision	unitless	Enumerated value ["Unimpaired", "Protanomaly", "Deuteranomaly", "Tritanomaly", "Protanopia", "Tritanopia"]
Left/Right eye near vision acuity	Jaeger scale	Near vision acuity expressed as corresponding value on the Jaeger scale, as if examined with the use of a Jaeger Chart [13]

Left/Right eye distance vision acuity	meters	Near vision acuity expressed in meters as if examined with the use of a Snellen Chart [14] (6/x meters)
Left/Right contrast sensitivity	logarithmic contrast value	Contrast sensitivity refers to the minimum contrast required for a person to perceive objects [15]. In the context of VUMRef, contrast sensitivity expressed as logarithmic contrast values, as if examined using the Pelli-Robson chart [16]
Left/Right eye superior peripheral vision	degrees	A person's peripheral visual field in the superior direction (upwards)*
Left/Right eye inferior peripheral vision	degrees	A person's peripheral visual field in the inferior direction (downwards)*
Left/Right eye nasal peripheral vision	degrees	A person's peripheral visual field in the nasal direction (towards the nose) *
Left/Right eye temporal peripheral vision	degrees	A person's peripheral visual field in the temporal direction (towards the respective side's temple) *

** Peripheral vision is described as a collection of the uniocular field of vision of a person, separated in four directions [17] [18].*

3.3 Mobility Information

This field includes all metrics pertaining to a person's flexibility, reach and strength, and anthropometric measurements, such as hip height and sitting height. As the metrics of this field determine the capabilities of the VH during the runtime of a simulation, each of the most prominent joints typically involved in those interactions is described by a collection of separate nodes describing its active range of motion (active ROM), meaning the joint's range of motion when consciously mobilized without the intervention of outside forces [11]. Similarly, VUMRef includes multiple metrics describing a person's strength as the amount of force they can exert under different circumstances, for example depending on whether that person is standing or sitting, pushing or pulling, using one or both arms, etc. The model also covers the physical capabilities of the lower body, such as walking speed, step length, and stair-climbing speed.

The information detailed in the field of Mobility is separated into two major categories (first level of distinction), those of Upper and Lower body mobility respectively, and then are further categorized depending on the limb or part of the body described (second level of distinction). The first level of distinction is presented in Figure 5, along with the nodes that do not fall under the second level of distinction, meaning they are directly related to the "Mobility" *Information* node, or the "Upper/Lower body mobility" *Structure* nodes.

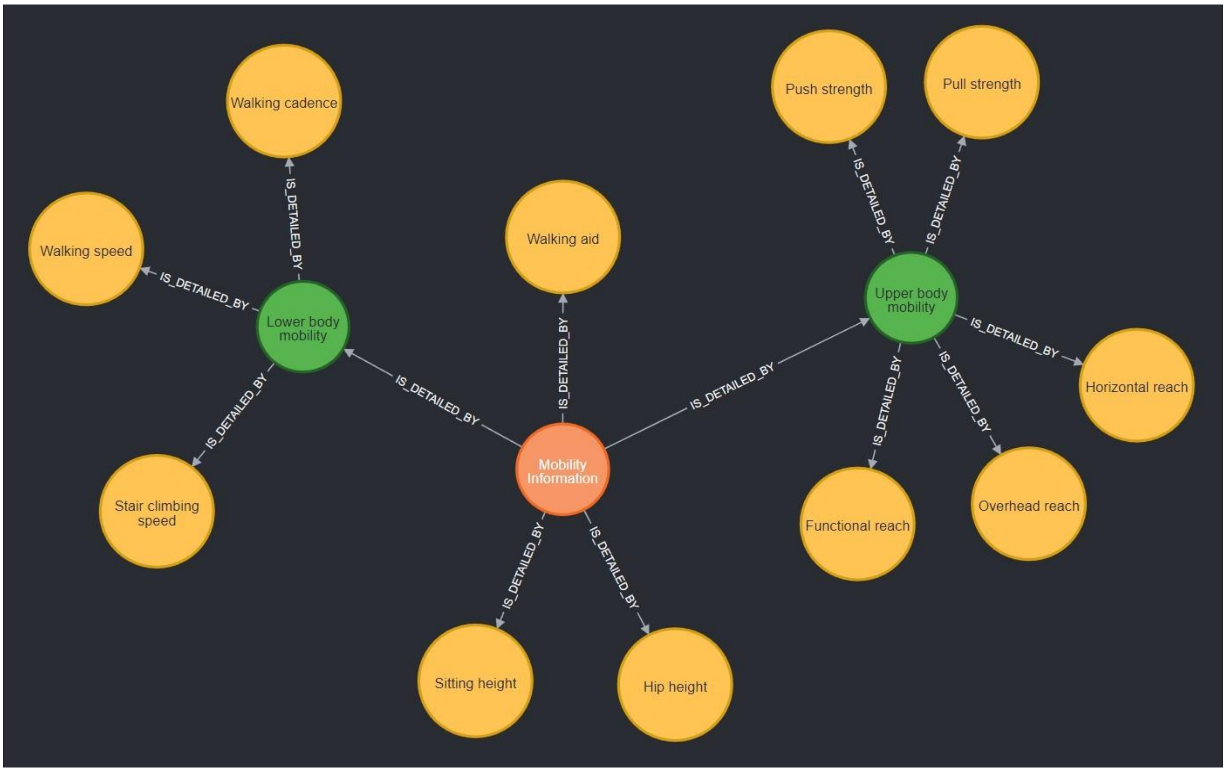

Figure 5. Mobility Information

The nodes attached directly to the "Mobility Information" node describe anthropometric measurements that do not strictly correlate to the upper or lower half of the body, and include **sitting height** [[19], [20] and **hip height** [21], along with a node referring to a person's dependence on walking aid devices, or lack thereof. Details about these nodes are presented in the following Table 6.

Table 6. Mobility Information

Property	Units	Notes
Walking aid	unitless	Enumerated value ["Independent", "Wheelchair", "Cane", "Walking stick", "Walking frame"]
Sitting height	centimeters	The distance the surface a person is sitting on, and the top of their head [19]
Hip Height	centimeters	The distance between the floor and the middle of the crotch area [21]

Similarly, the metrics regarding upper body mobility without further categorization, include anthropometric measurements detailing upper body reach, specifically horizontal reach [22], overhead reach [23], and functional reach [24], [25].

Horizontal reach, in the context of VUMRef, is given the definition of functional grip reach meaning the vertical distance from the vertical plane of a person's back, to the middle of their grip [26]. The person is assumed to be standing erect with their back against the wall, with their hand in a grip and extended horizontally forward.

Overhead reach is similarly given the definition of vertical grip reach meaning the vertical distance from a horizontal standing surface to the middle of their grip [26]. The person is assumed to be standing erect, with their hand in a grip and held straight overhead.

Functional reach is defined as established by Duncan et al. [24], as the maximal distance one can reach forward beyond arm's length, while maintaining a fixed base of support in the standing position. As established by Kage et al. [25], the distance is measured finger-to-finger, and is presented in Figure 6 (distance marked as (1)).

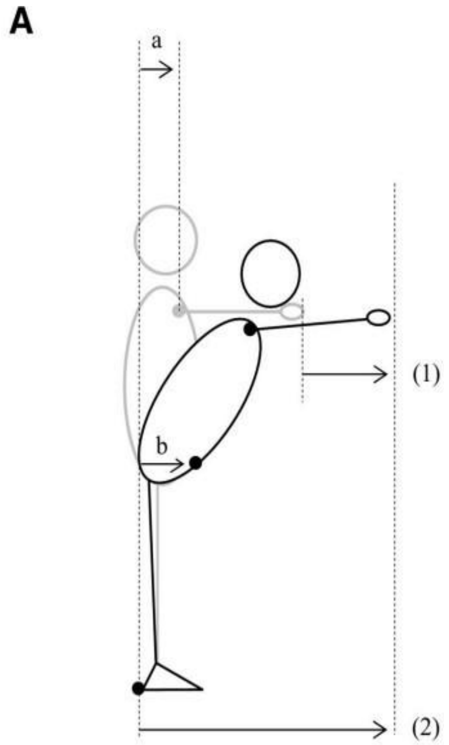

Figure 6. Functional reach visualization

Pull and **push strength** are defined as the maximum isometric strength the person can exert with both hands at a medium height (100 cm from the ground) with that person's lower body remaining stable [22]. All nodes describing the strength and reach metrics of the upper body as defined above, are presented in Table 7

Table 7. Upper Body Mobility

Property	Units	Notes
Horizontal reach	centimeters	The horizontal reach of a person
Overhead reach	centimeters	The overhead reach of a person
Functional reach	centimeters	The functional reach of a person
Pull strength	newtons	The maximum isometric two-handed force a person can exert when pulling with both hands at a height of 100 cm [22]
Push strength	newtons	The maximum isometric two-handed force a person can exert when pushing with both hands at a height of 100 cm [22]

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Table 7. Upper Body Mobility

Property	Units	Notes
Horizontal reach	centimeters	The horizontal reach of a person
Overhead reach	centimeters	The overhead reach of a person
Functional reach	centimeters	The functional reach of a person
Pull strength	newtons	The maximum isometric two-handed force a person can exert when pulling with both hands at a height of 100 cm [22]
Push strength	newtons	The maximum isometric two-handed force a person can exert when pushing with both hands at a height of 100 cm [22]

As with upper body mobility, the nodes concerning lower body mobility codify valuable information about the physical capabilities of the VH to be simulated, including **walking speed** [27], [28], **stair climbing speed** [29], and **walking cadence** [30]. Details about those metrics are presented in Table 8.

Table 8. Lower Body Mobility

Property	Units	Notes
Walking speed	meters/second	
Stair climbing speed	meters/second	The average speed maintained by a person ascending a flight of stairs [32]
Walking cadence	steps/minute	The rate of stepping when a person is walking with moderate intensity [33]

The *Structure* nodes of ”Upper/Lower body mobility” are further related to *Structure* nodes representing specific limbs. The corresponding parts of VUMRef are presented in the following subsections.

3.3.1 Upper Body Mobility

Apart from the metrics presented in Figure 5, the physical capabilities of the upper body are additionally described by the limits and measurements of each arm when examined separately. The relevant information included in the VUMRef includes a set of metrics pertaining to the physical strength displayed when tested under various circumstances and grips, as well as three separate sets of metrics describing the flexibility of the 3 major joints of the arm respectively (wrist, elbow, shoulder). These sets are grouped together by their relationship to the appropriate *Structure* nodes, and a visualization of this structure is presented in Figure 7. Note that while the figure is annotated as a description of the left arm, the set of variables that describes the right arm is identical in structure.

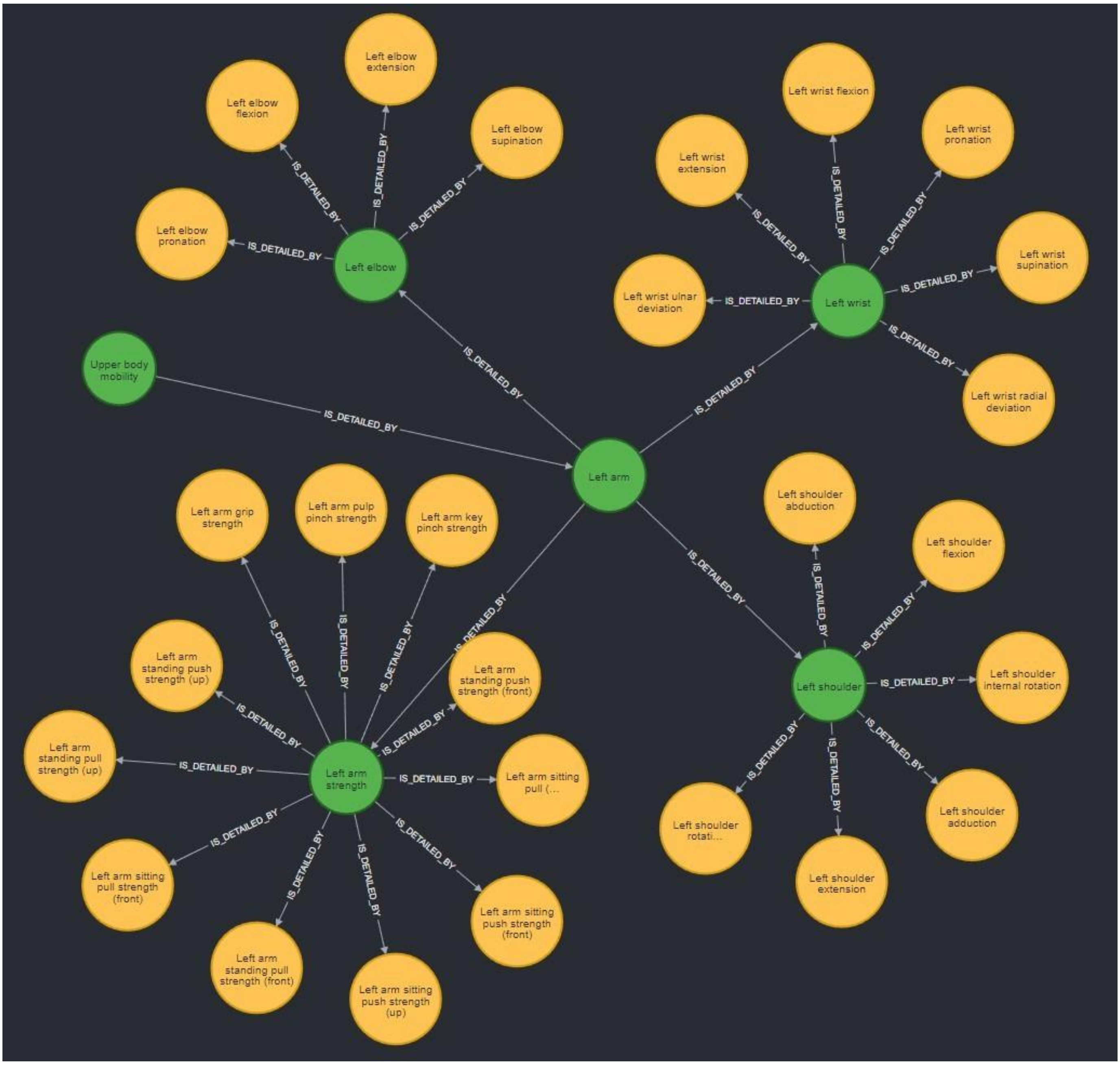

Figure 7. Mobility of left arm (right arm identical)

The ”Left/Right arm strength” *Structure* node is related to a group of nodes collectively covering a person's strength when using one arm. Each of these nodes measures the strength exhibited by a person in one combination of the following circumstances [32]:

- The person is standing up or sitting down,
- The person is pulling or pushing,
- The person's arm is positioned extended in front of the chest, or straight overhead.

In addition to these, three more nodes record an individual's hand strength in three different forms, namely **grip strength**, **key pinch strength**, and **pulp pinch strength** [32].

Table 9 details all the *Metric* nodes related to ”Left/Right arm strength”.

Table 9. Left/Right arm strength

Property	Units	Notes
Left/Right arm grip strength	newtons	The strength of an individual's hand when held in a grip [32]
Left/Right arm key pinch strength	newtons	The strength of an individual's hand when held in a key pinch grip [32]
Left/Right arm pulp pinch strength	newtons	The strength of an individual's hand when held in a pulp pinch grip [32]
Left/Right arm standing pull strength (front)	newtons	The force a standing person can exert when pulling an object with their arm extended directly in front of them [31]
Left/Right arm standing pull strength (up)	newtons	The force a standing person can exert when pulling an object with their arm extended straight upwards [31]
Left/Right arm standing push strength (front)	newtons	The force a standing person can exert when pushing an object with their arm extended directly in front of them [31]
Left/Right arm standing push strength (up)	newtons	The force a standing person can exert when pushing an object with their arm extended straight upwards [31]
Left/Right arm sitting pull strength (front)	newtons	The force a sitting person can exert when pulling an object with their arm extended directly in front of them [31]
Left/Right arm sitting pull strength (up)	newtons	The force a sitting person can exert when pulling an object with their arm extended straight upwards [31]
Left/Right arm sitting push strength (front)	newtons	The force a sitting person can exert when pushing an object with their arm extended directly in front of them [31]
Left/Right arm sitting push strength (up)	newtons	The force a sitting person can exert when pushing an object with their arm extended straight upwards [31]

As mentioned earlier, the mobility of a person's joints is defined as their active range of motion (ROM), and the metrics that comprise ROM vary from joint to joint, as outlined in Figure 7.

The metrics used for the shoulder joints are illustrated in Figure 8 [33], and the respective properties are described in Table 10.

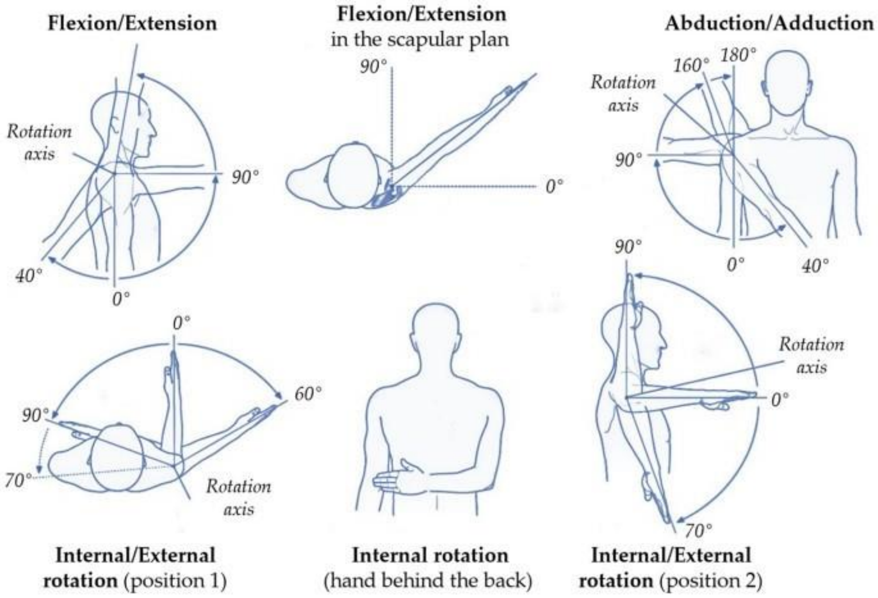

Figure 8. Shoulder range of motion [34]

Table 10. Left/Right shoulder

Property	Units	Notes
Left/Right shoulder flexion	degrees	The shoulder's range of flexion
Left/Right shoulder extension	degrees	The shoulder's range of extension
Left/Right shoulder abduction	degrees	The shoulder's range of abduction
Left/Right shoulder adduction	degrees	The shoulder's range of adduction
Left/Right shoulder external rotation	degrees	The shoulder's range of external rotation
Left/Right shoulder internal rotation	degrees	The shoulder's range of internal rotation
Left/Right arm sitting push strength (up)	Newtons	The force a sitting person can exert when pushing an object with their arm extended straight upwards [31]

Figure 9 illustrates the various movements measured, and Table 11 details the properties of the elbow mobility nodes [35].

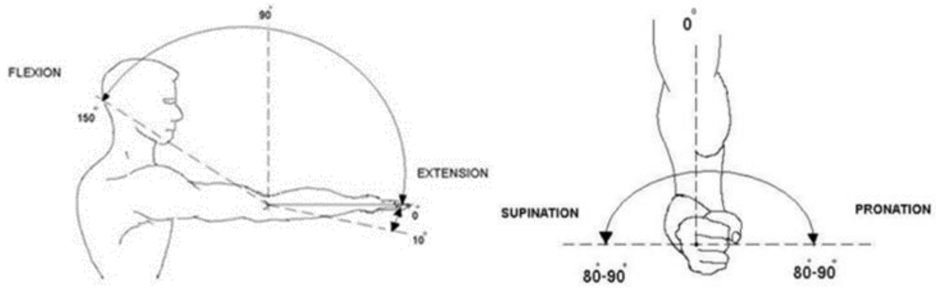

Figure 9. Elbow range of motion [35]

Table 11. Left/Right elbow

Property	Units	Notes
Left/Right elbow flexion	degrees	The elbow's range of flexion
Left/Right elbow extension	degrees	The elbow's range of extension
Left/Right elbow supination	degrees	The elbow's range of supination
Left/Right elbow pronation	degrees	The elbow's range of pronation

Figure 10 illustrates the possible motions typically associated with wrist mobility while Table 12 details the properties associated with the respective nodes [36].

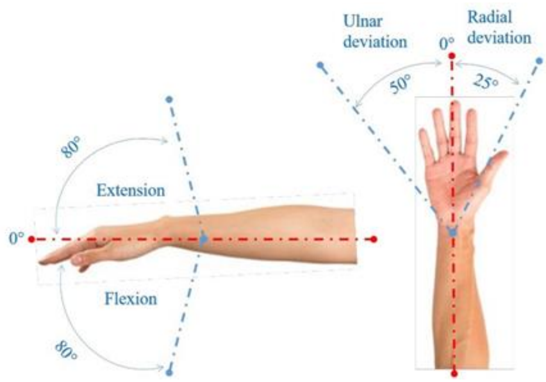

Figure 10. Wrist range of motion [36]

Table 12. Left/Right wrist

Property	Units	Notes
Left/Right wrist flexion	degrees	The wrist’s range of flexion
Left/Right wrist extension	degrees	The wrist’s range of extension
Left/Right wrist ulnar deviation	degrees	The wrist’s range of ulnar deviation
Left/Right wrist radial deviation	degrees	The wrist’s range of radial deviation

3.3.2 Lower Body Mobility

Structurally similar to upper body mobility, lower body mobility is detailed by a group of nodes related to the *Structure* ”Lower body mobility” node (see Figure 5). Apart from the metrics directly related to ”Lower body mobility”, as detailed in Table 8, which describe an individual’s walking capabilities, each of the legs is similarly described by a cluster of nodes measuring the flexibility of the various leg joints (hip, knee, ankle). The structure and relationships of these nodes are depicted in Figure 11.

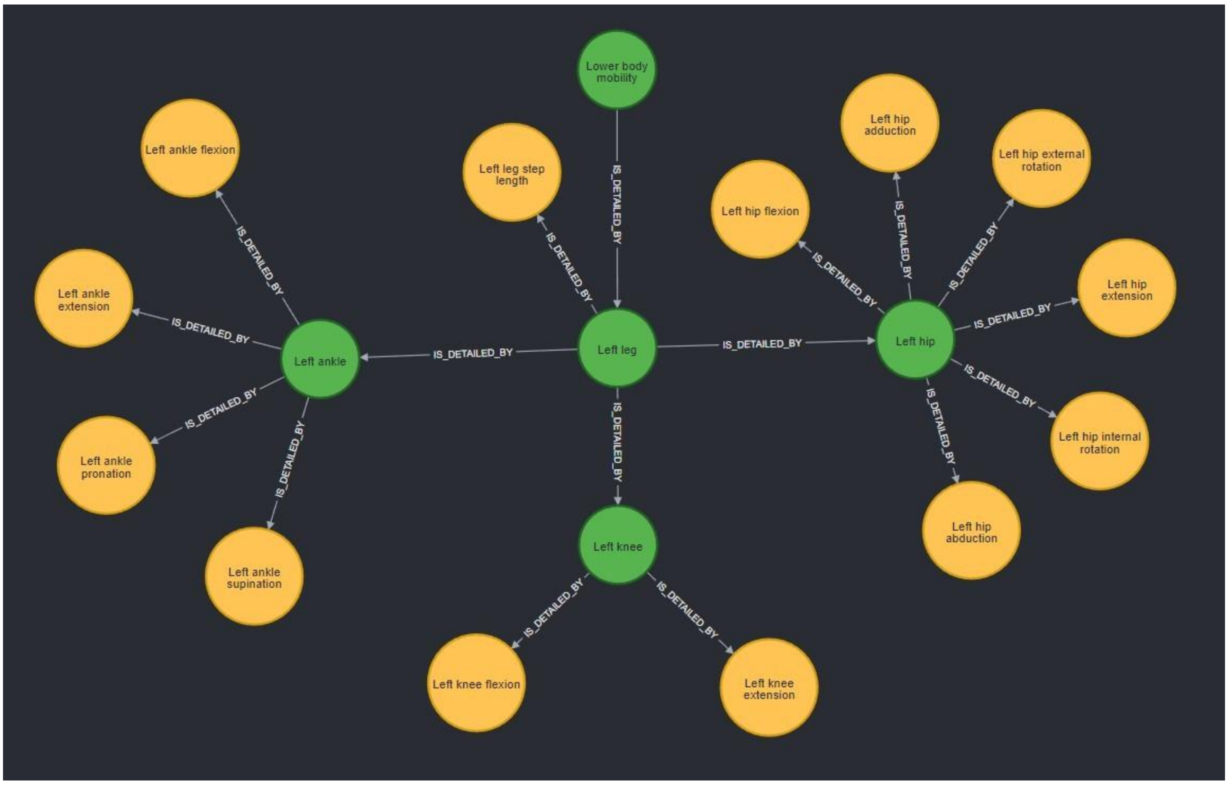

Figure 11. Leg mobility (left leg pictured, right leg identical)

Along with the Structure nodes representing the joints, each leg is also described by a Metric node detailing a person’s step length. While related literature sometimes measures stride length [37], [38] in similar anthropometric contexts, step length was chosen as a metric because of two reasons: a) stride length can be calculated by adding the step lengths of both legs, and b) in cases where the step length of one leg might significantly differ from the other (e.g. cases of serious injury, diseases that impair mobility, genetic conditions, etc.), separate step length metrics offer a more accurate formalization of a person’s capabilities. The structure of this node is presented in Table 13.

Table 13. Left/Right leg step length

Property	Units	Notes
Left/Right wrist flexion	degrees	The wrist’s range of flexion
Left/Right wrist extension	degrees	The wrist’s range of extension

Left/Right wrist ulnar deviation	degrees	The wrist's range of ulnar deviation
Left/Right wrist radial deviation	degrees	The wrist's range of radial deviation

In regards to the mobility of the lower body's joints, it is measured similarly to that of joints in the upper body, i.e., by measuring the active ROM of that joint in all directions. All relevant metrics concerning hip mobility [39] are presented in Table 14.

Table 14. Left/Right hip

Property	Units	Notes
Left/Right hip flexion	degrees	The hip's range of flexion
Left/Right hip extension	degrees	The hip's range of extension
Left/Right hip abduction	degrees	The hip's range of abduction
Left/Right hip adduction	degrees	The hip's range of adduction
Left/Right hip internal rotation	degrees	The hip's range of internal rotation
Left/Right hip external rotation	degrees	The hip's range of external rotation

Active range of motion for the knees is measured by two metrics, which are presented in Table 15. It is noted that extension is normally not possible, however some slight range of motion is possible for some people exhibiting hyperextension in the knee [39], [40].

Table 15. Left/Right knee

Property	Units	Notes
Left/Right knee flexion	degrees	The knee's range of flexion
Left/Right knee extension	degrees	The knee's range of extension

According to [41], the ankle mobility nodes describing active ROM, are visualized in Figure 12, and are presented as node properties in Table 16.

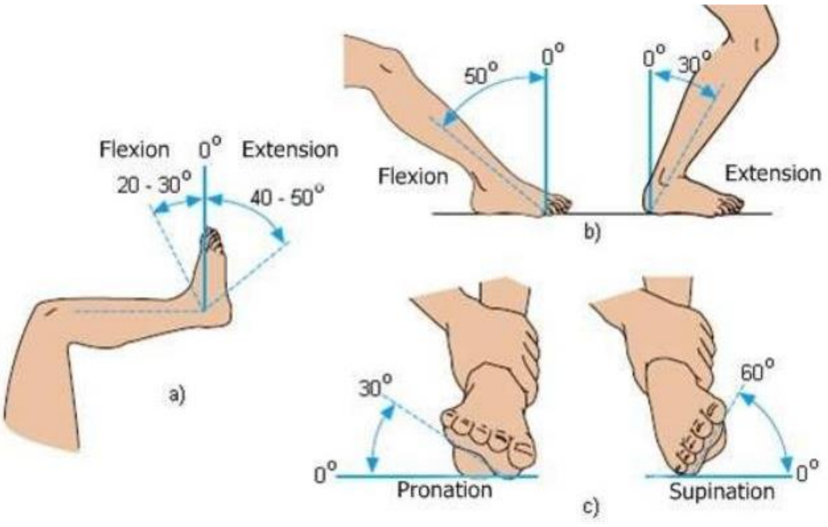

Figure 12. Ankle range of motion [41]

Table 16. Left Right ankle

Property	Units	Notes
Left/Right ankle flexion	degrees	The ankle's range of flexion
Left/Right ankle extension	degrees	The ankle's range of extension
Left/Right ankle pronation	degrees	The ankle's range of pronation
Left/Right ankle supination	degrees	The ankle's range of supination

3.4 Auditory Information

This section of auditory information describes a person's hearing capabilities by measuring the lowest threshold of volume at which sound can be detected at different frequencies, a set of information corresponding to a person's audiogram [42], [43]. The information is kept separately for each ear, The structure of the relevant nodes are presented in Figure 13 while the full explanation for each *Metric* is provided in Table 17.

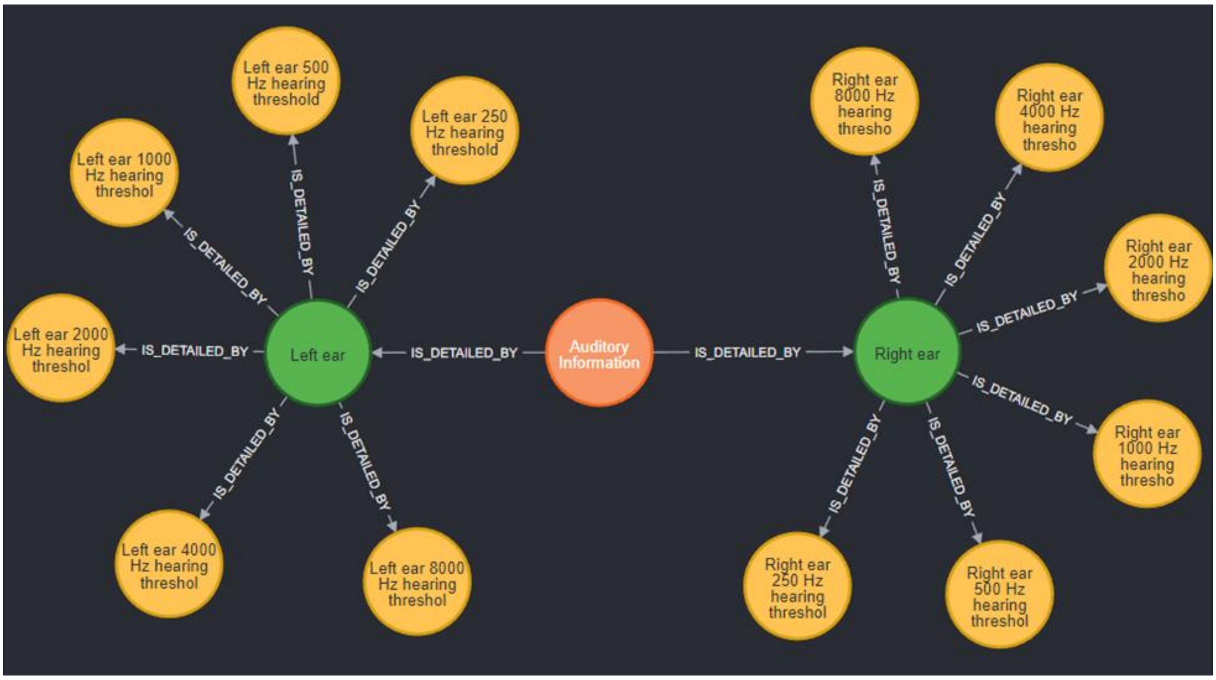

Figure 13. Auditory Information

Table 17. Left/Right ear

Property	Units	Notes
Left/Right ear 250 Hz hearing threshold	decibels	The volume threshold at which a person can detect sounds, at a frequency of 250 Hz
Left/Right ear 500 Hz hearing threshold	decibels	The volume threshold at which a person can detect sounds, at a frequency of 500 Hz
Left/Right ear 1000 Hz hearing threshold	decibels	The volume threshold at which a person can detect sounds, at a frequency of 1000 Hz
Left/Right ear 2000 Hz hearing threshold	decibels	The volume threshold at which a person can detect sounds, at a frequency of 2000 Hz
Left/Right ear 4000 Hz hearing threshold	decibels	The volume threshold at which a person can detect sounds, at a frequency of 4000 Hz
Left/Right ear 8000 Hz hearing threshold	decibels	The volume threshold at which a person can detect sounds, at a frequency of 8000 Hz

3.5 Cognitive Information

The information formalized in the cognitive metrics of VUMRef describe a person's mental capabilities and cognitive skills relevant to their interaction with built environments. These metrics include indicative values for a person's reaction speed, i.e. preparation time and initiation time [44], [45], as well as metrics pertaining to a person's language-related skills, including reading and writing speed [46], [47], both needed skills for navigating and completing basic tasks in any environment. It is noted that measuring reaction speed might be minimally relevant in common interactions between users and environments, but become critical when assessing spaces in the context of emergency situations and safety hazard evaluation.

In addition, VUMRef includes two Metric nodes describing an individual's score on established tests of mental aptitude, specifically the Digit Symbol Substitution Test (DSST) [48], [49] and the Modified Mini-Mental State Examination (3MS) [50], [51], [52]. Declining performance on those two tests has been correlated with aging and lower education levels, while also used as a screening tool for signs dementia and other cognitive disabilities [53], [54], [55], [56], [57].

The DSST is a subtest of the Wechsler Adult Intelligence Scale, Revised (WAIS-R) [58], and consists of a look-up table with pairs of symbols and their assigned numbers, and a section with similar boxes with the symbols missing. Examinees are required to fill as many of these boxes as they can in a given time (usually 90-120 seconds [49], [59]), and the number of correct answers is recorded as their score. Although there are still discussions to be had about the exact skills and capabilities specifically measured by this test [60], [61], [62], the DSST has seen great use as a neuropsychological evaluation tool, examining an individual's attention span, motor speed and perceptual speed [48], [57], and it is noted for its sensitivity to the presence of cognitive disabilities, dementia and other forms of neurological degeneration [48], [49].

Similarly, the 3MS is an expansion upon the previously used Mini-Mental State Examination (MMSE) [51], and it is used as an examination tool for the detection of dementia and cognitive disability [53], [63]. It consists of various verbal and written questions aimed toward testing an individual's executive mental functions, including working memory, semantic fluency and general cognitive aptitude [52], [56], and it is valued for its detailed scoring system (ranges 0-100 compared to the upper limit of 30 for the MMSE), ease of administration and test-retest reliability [50], [53], [54], [64].

Figure 14 presents the structure of the Cognitive Information field while the Table 18 details the Metrics described above.

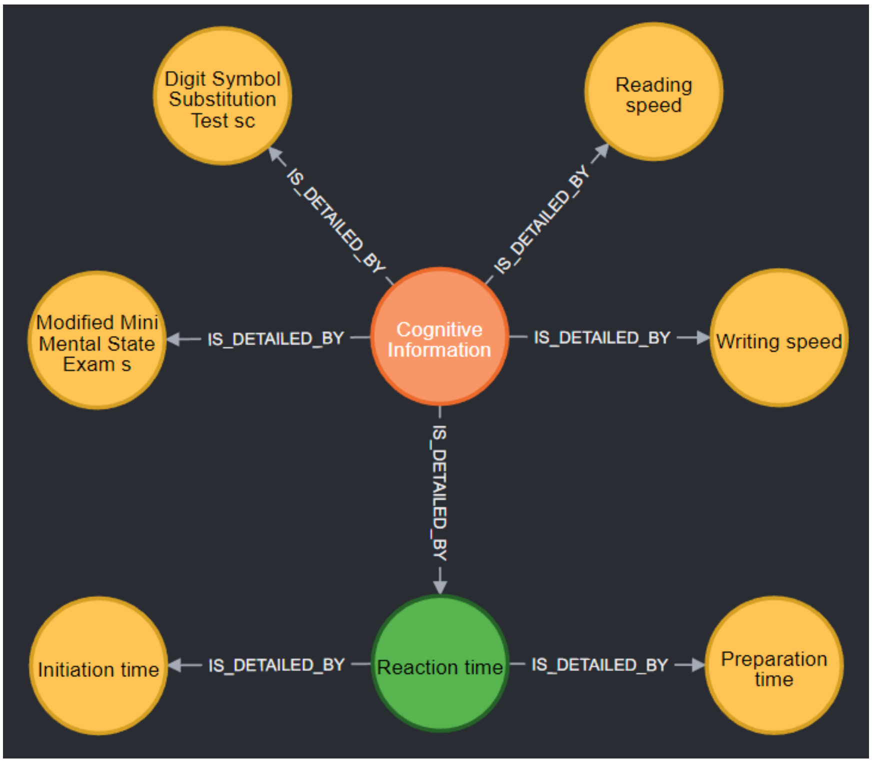

Figure 14. Cognitive Information

Table 18. Cognitive Information

Property	Units
Digit Symbol Substitution Test score (DSST)	correct answers in 90 seconds
Modified Mini Mental State Exam score	unitless
Writing speed	letters per minute
Reading speed	words per minute
Preparation time	milliseconds
Initiation time	milliseconds

4 Disabilities Reference Model

The VUMRef is complemented by a similarly structured AccesS Disabilities Reference (hereafter referred to as ADRef), which aggregates of a representative subset of the most prevalent disability types. The ADRef is designed to allow users of all backgrounds to accommodate individuals with different levels of capability within human-environment simulated interactions. Except direct modification of metric values which leaves room for experts to tailor a user profile according to the needs of each simulation scenario, the inclusion of the ADRef significantly expands the scope of assessment as it recognizes that accessibility is experienced differently depending on the user's physical, sensory, or cognitive abilities.

The structure of ADRef is similar to that of VUMRef, with a unique *Reference* node serving as root of the graph, and connected with various *Disability* nodes, representing general types of disabilities. *Disability* nodes are related to either *Specification* nodes, representing specific subtypes of that same disability, or *Effect* nodes each of whom represent the effects of a *Disability/Specification* at different stages of severity. Note that each *Specification* node (or *Disability*, whenever there are no further subtypes) is connected to at least one *Effect* node, for those cases where severity is not a valid parameter (e.g., an individual's dependence on a wheelchair does not allow for different grades; a person is either considered wheelchair-bound, or not).

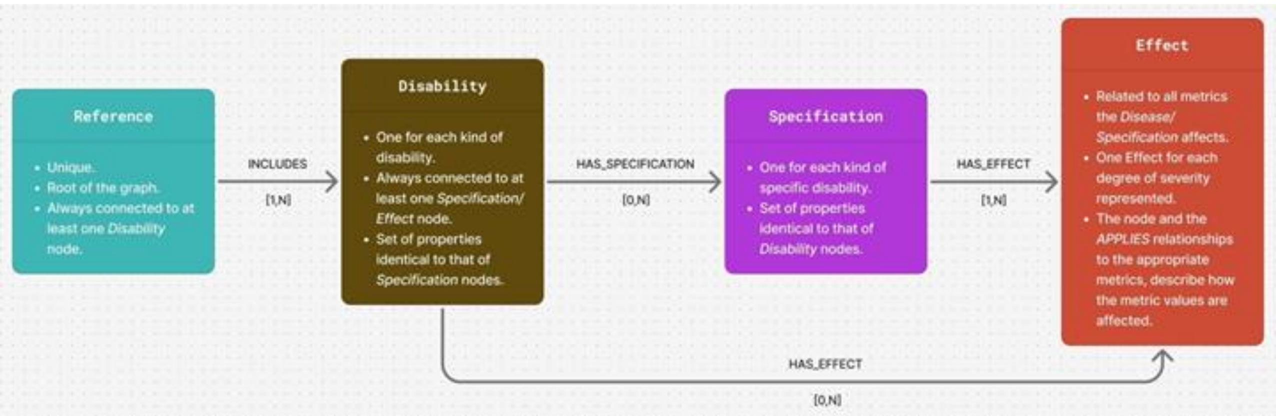

Figure 15. ADRef structure

Figure 15 presents an abstraction of ADRef's structure. Hereafter all nodes included in figures are colored according to their type: cyan for Reference nodes, brown for Disability nodes, purple for Specification nodes, red for Effect nodes. Figure 16 provides an example of that structure in the *Disability* of "Osteoarthritis".

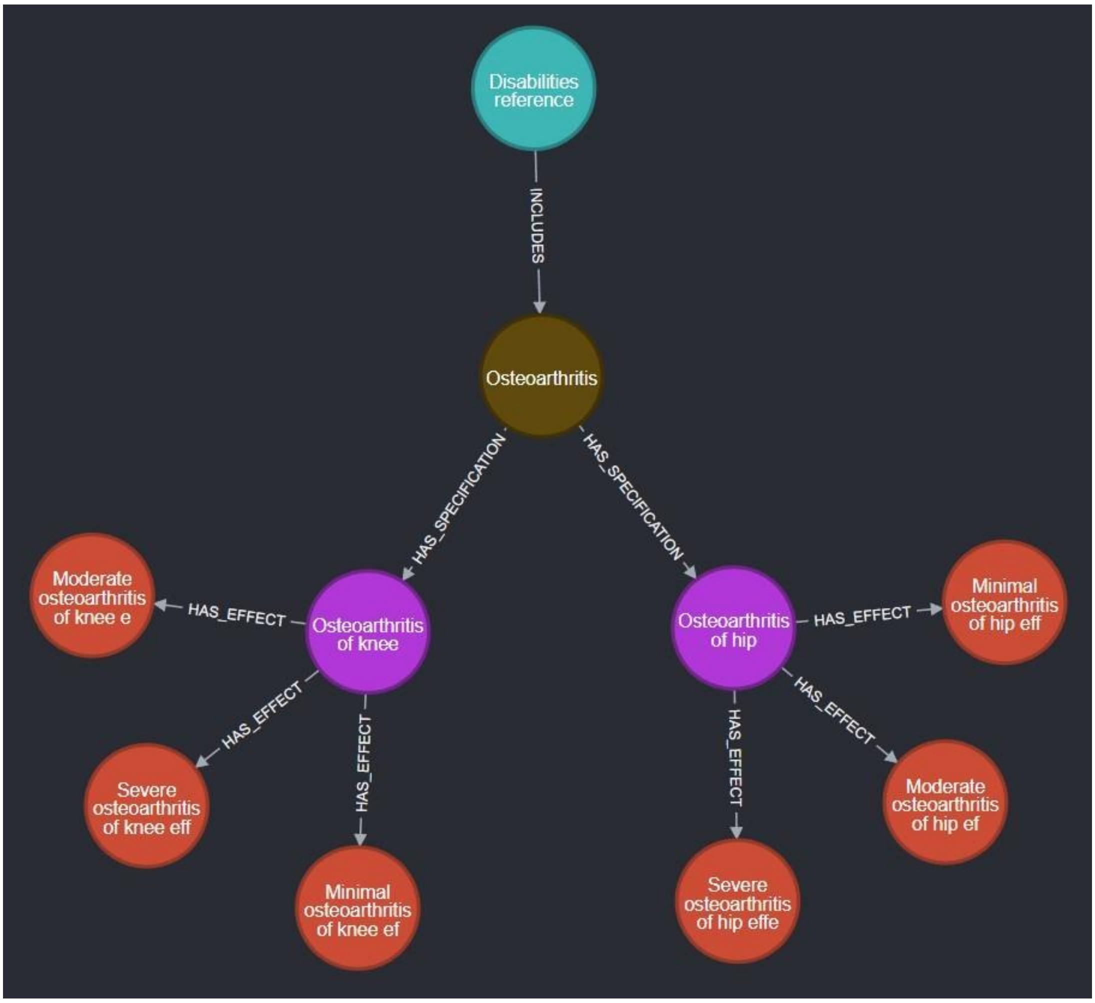

Figure 16. ADRef formalization of ”Osteoarthritis”

Each *Effect* node is a formal representation of the way a disability, or specification affects the user’s profile and consequently the corresponding VH, with one node for each degree of severity. These *Effect* nodes are related to all the *Metric* nodes affected by the corresponding condition by an *APPLIES* relationship. The *Effect* node along with the *APPLIES* relationship collectively describe the value adjustment applied to a metric’s value which is affected by that disability.

The following subsections detail the properties of each type of node included in ADRef and explains their role in the broader context of the AccesS project.

4.1 Disabilities & Specifications

Disability and *Specification* nodes make up the core of the Disabilities Reference. They share an identical set of properties codifying information about the disorders they represent, as those are described in the latest iteration of the International Classification of Disease (ICD-11 [65] at the time of writing). The structure of *Disability* and *Specification* nodes are described in Table 19.

Table 19. Disability/Specification node structure

Property	Value type	Notes	Example disability ("Myopia")
full_term	string	The ICD full term referring to the condition	"Myopia"
alt terms	list<string>	Alternative terms used by the ICD to refer to the condition	["Near-sightedness", "Short-sightedness"]
icd_ref	string	The unique WHO's Foundation URI referring to the condition in question	"http://id.who.int/icd/entity/1666440799"
desc	string	The free-text description accompanying the condition according to the ICD reference	"A refractive error in which..."

It is worth noting that all value properties presented in Table 19 are curated from the ICD reference, including the '*desc*' field, which was previously left up to the user, with the latter change being because of the difference in purpose between VUMRef and ADRef; the Users Model Reference is used to model User Profiles whose values are by definition sourced by users. In contrast, the Disabilities Reference is an aggregation of valuable information about various disabilities and conditions that a user may include in a profile without relevant expertise in the field. It is therefore accordingly designed to provide information to potential users instead of the users providing information to the model.

4.2 Reference & Effects

As previously mentioned, *Effect* nodes are connected to the metrics a given condition adjusts, with the node itself in combination with the relationship between them describing the adjustment. Figure 17 presents the abstracted interaction between the *Effect* nodes of ADRef and the *Metric* nodes of the VUMRef.

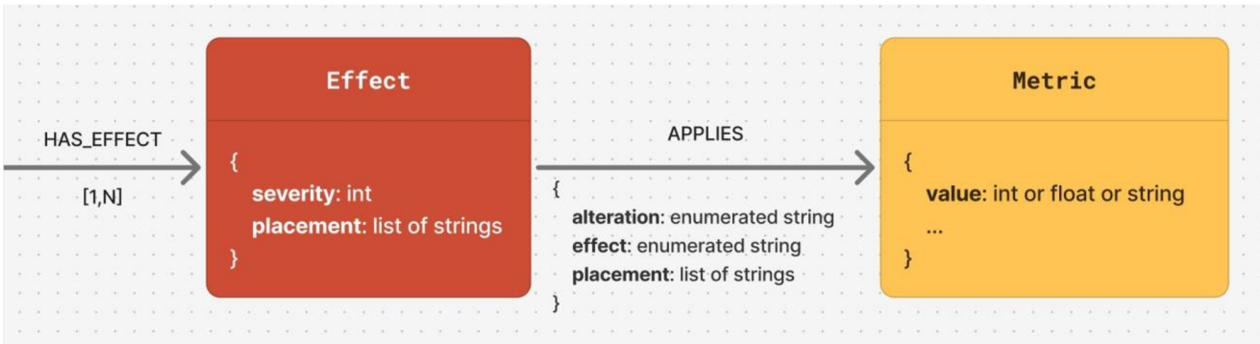

Figure 17. Effect - Metric interaction

The properties of *Metric* nodes are presented in previous sections (see Table 2, Table 3), and the properties for Effect nodes while the HAS_EFFECT relationships are presented in Table 20 and Table 21 respectively.

Table 20. Effect node structure

Property	Value type	Notes	Example disability effect ("Mild Myopia")
severity	int	Severity of effect described as an integer. Starting at 1, value increases with severity (where gradation is supported).	1
placement	list<string>	The distinct options of placement for disabilities wherever that choice applies.	["Left eye"]

Table 21. Properties of *APPLIES* relationship

Property	Value type	Notes	Example: "Minimal osteoarthritis of knee effects" - APPLIES - "Left knee flexion"
value	string or int	The value of the modification to be applied to the metric.	10
effect	enumerated string	Describes the type of modification applied to the value by the disability.	"DECREASE"
alteration	enumerated string	Relationship property that determines whether the effect described by the respective property will be applied as an absolute value, or a percentage of the existing metric value.	"PERCENTAGE"
placement	list<enumerated string>	A subset of the placement options of the corresponding Effect, denoting which cases of placement include the value shift being described.	["Left knee", "Both knees"] *#The value of the metric "Left knee flexion" is affected when "Osteoarthritis of knee" is applied to the left knee, or to both knees.*

The example that Table 21 depicts (4th column) can be read as "Apply a 10% decrease to the value of the node "Left knee flexion", when minimal osteoarthritis affects only the left knee, or both knees of a person". The use of enumerated strings serves the dual purpose of allowing for the easy application of disabilities to User Profiles by external agents, while maintaining human and machine readability. Figure 18 presents the example of "Minimal osteoarthritis of knee", and how it relates to the metrics it affects.

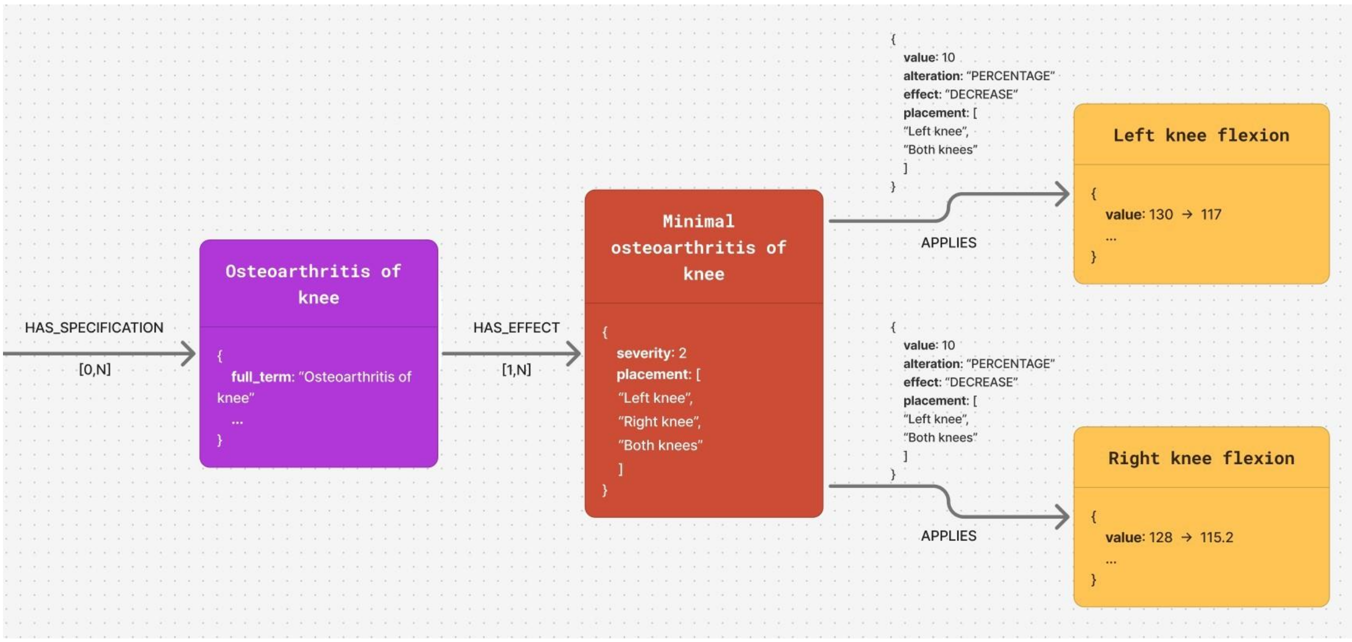

Figure 18. Minimal osteoarthritis of knee

Breaking down the example above, the *Specification* node of ”Osteoarthritis of knee” is related to *Effect* nodes of different possible severities that could affect a User Profile. The example of minimal osteoarthritis has a severity of 2, with similar nodes available for ”Doubtful osteoarthritis” (severity = 1), ”Moderate osteoarthritis”, (severity = 3), etc. The node also includes the *placement* property, indicating that osteoarthritis can be present in one, or both knees. The *Effect* node is in turn related to all the metrics affected by this form of osteoarthritis, with the respective relationships formalizing the shift in value that entails. As explained above, in this case the effect can be plainly described as a 10% decrease in knee flexion, and the sample values of the metrics are adjusted accordingly.

The enumerated values supported by the respective properties of *APPLIES* relationships are also included in ADRef. The complete set of possible options for the *effect* and *alteration* properties of APPLIES relationships are included as properties in the *Reference* node at the root of ADRef (see Figure 15), and the current state of those properties is detailed in Table 22.

Table 22. Reference node properties

Property	Possible values	Notes
effects	”INCREASE”	Increase the metric by the accompanying amount.
	”DECREASE”	Decrease the metric by the accompanying amount.
	”SET”	Replace the existing value of the metric, by the value indicated in the relationship properties.
alterations	”ABSOLUTE”	Apply the modification of the Metric value as an absolute value.
	”PERCENTAGE”	Apply the modification of the Metric value as a percentage upon its existing value (cannot be used alongside a ”SET” alteration value, only for ”INCREASE”/”DECREASE”).
	”INCREASE”	Increase the metric by the accompanying amount.

5 User Profile samples

Having established all the necessary building blocks of VUMRef and ADRef, this section presents indicative samples of User Profiles corresponding to distinct personas, with metric values informed by their anthropometric and demographic information.

More specifically, two distinct personas have been created to clearly outline the characteristics of two potential user profiles in order to demonstrate the core functionality of the reference models (VUMRef and ADRef) embedded in the GUI Editor.

5.1 User Profile A: Female with visual disability

The first User Profile refers to a woman named Mirae Solin. She is 23 years old, 160cm tall, weighing 55kg (see Figure 19). Mirae has a vision disability, namely she is color blind, experiencing tritanomaly, a form of color vision deficiency that affects her perception of blue and yellow hues. Figure 20 visually details the specific disability characteristics registered for Mirae Solin within the GUI Editor, while the complete, underlying data - including all parameters for the specific User Profile - is formally presented in the JSON format incorporated in Annex A. The 3D representation of Mirae Solin is presented in Figure 21.

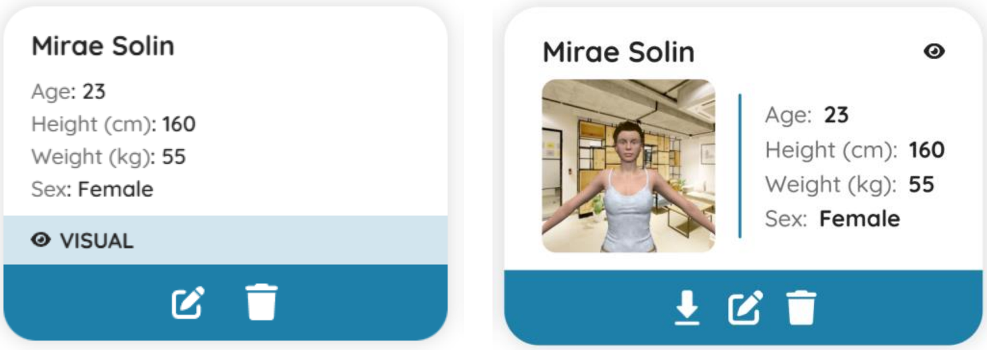

Figure 19. General information of the User Profile A

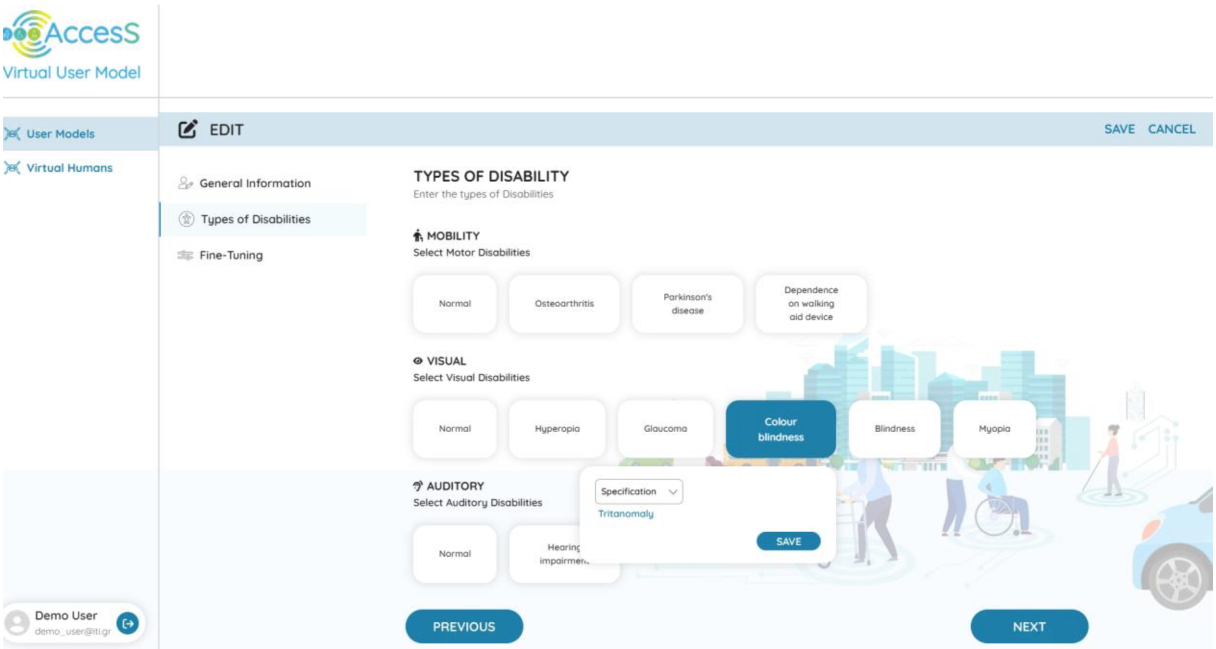

Figure 20. Types of Disabilities of the User Profile A

Figure 21. 3D representation of the User Profile A

5.2 User Profile B: Male with motor disability

The second User Profile refers to a man named John Doe. He is 45 years old, 195cm tall, weighing 150kg (Figure 22). John has a motor disability, namely moderate osteoarthritis at both knees and uses a wheelchair. Figure 23 and Figure 24 visually detail the specific disability characteristics registered for John within the GUI Editor, while the complete, underlying data - including all parameters for the specific User Profile - is formally presented in the JSON format incorporated in Annex B. The 3D representation of Jhon Doe is presented in Figure 25.

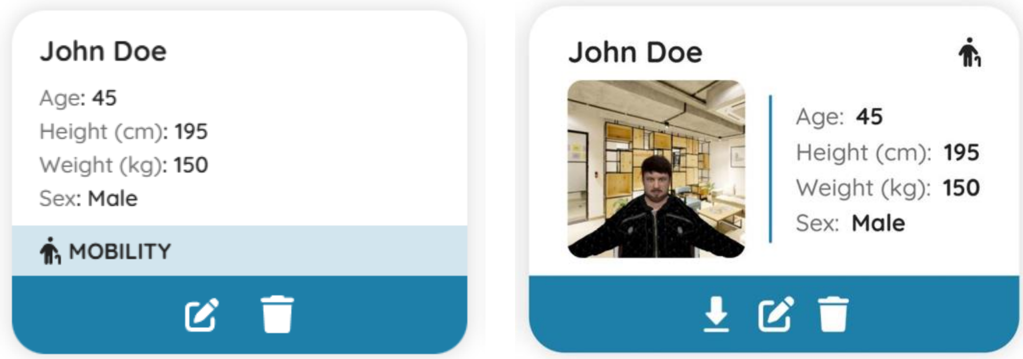

Figure 22. General information of the User model B

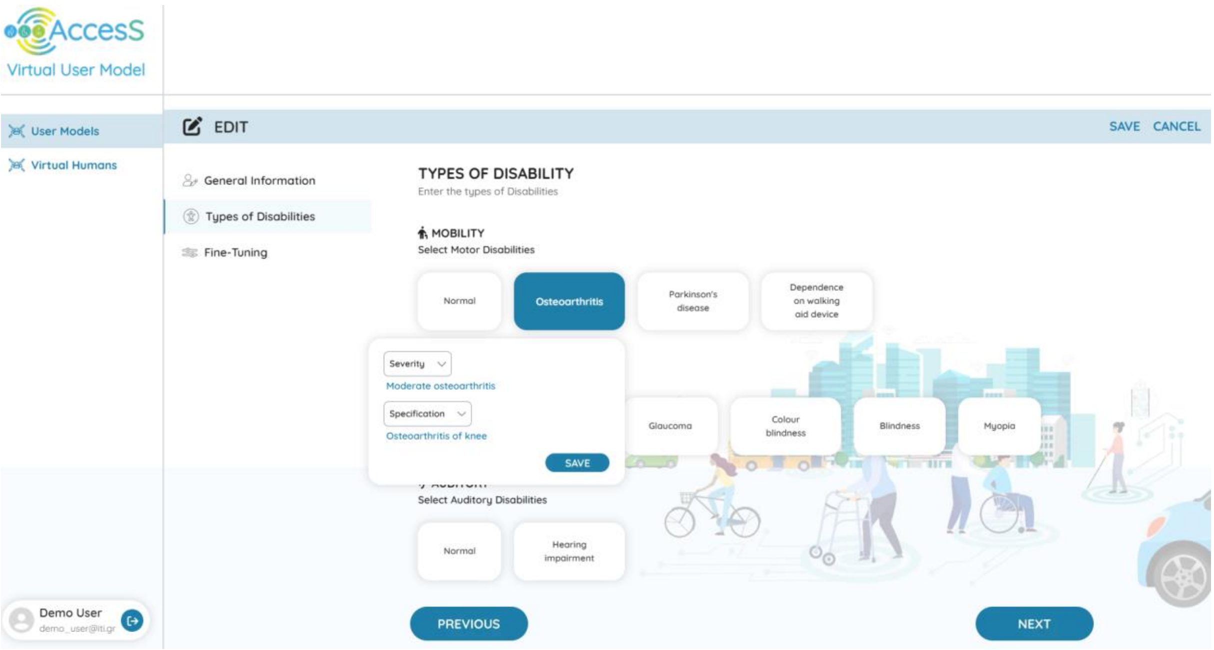

Figure 23. Types of Disabilities of the User Profile B

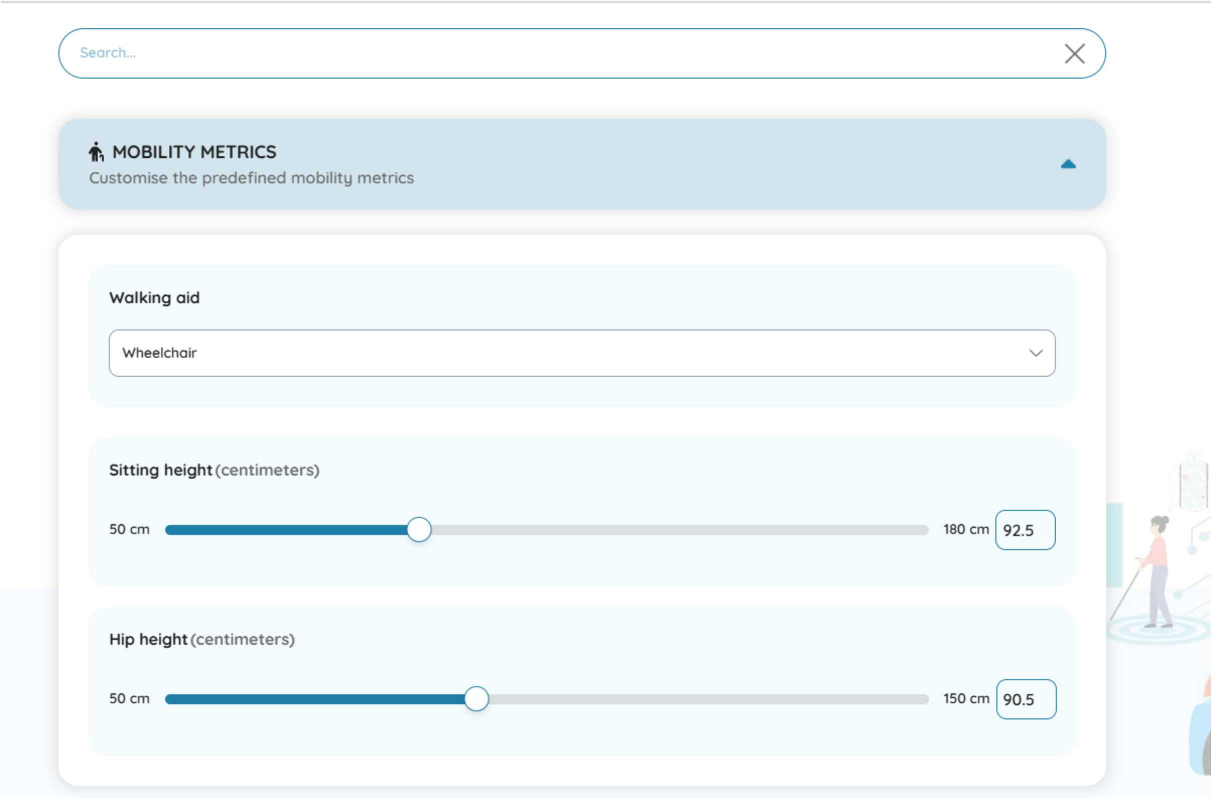

Figure 24. Mobility Metrics fine-tuning

Figure 25. 3D representation of the User Profile B

6 A Toolchain for the Implementation of Virtual Humans (VH)

Virtual Humans (VHs) constitute the three-dimensional (3D) embodiments of Virtual User Models (VUMs). In the context of the AccesS project, the goal of improving accessibility for people with disabilities requires realistic, diverse, and adaptable digital human representations.

Each VUM describes an individual profile, including physical characteristics and functional capabilities. Translating this multidimensional information into a corresponding 3D representation necessitates a flexible and parameterised approach to VH modelling. To address this requirement, a dedicated toolchain was developed to produce modular and fully customizable 3D human models, referred to as *Base Models*. These *Base Models* act as the foundational digital entities that can adapt their geometry, materials, and animations according to the descriptive parameters contained in the underlying VUM (see Figure 26). The developed *Base Models* are stored in `.glb` format and serve as foundational assets from which VHs are produced. Each model includes the necessary structural, geometric, and material components to support customization and animation.

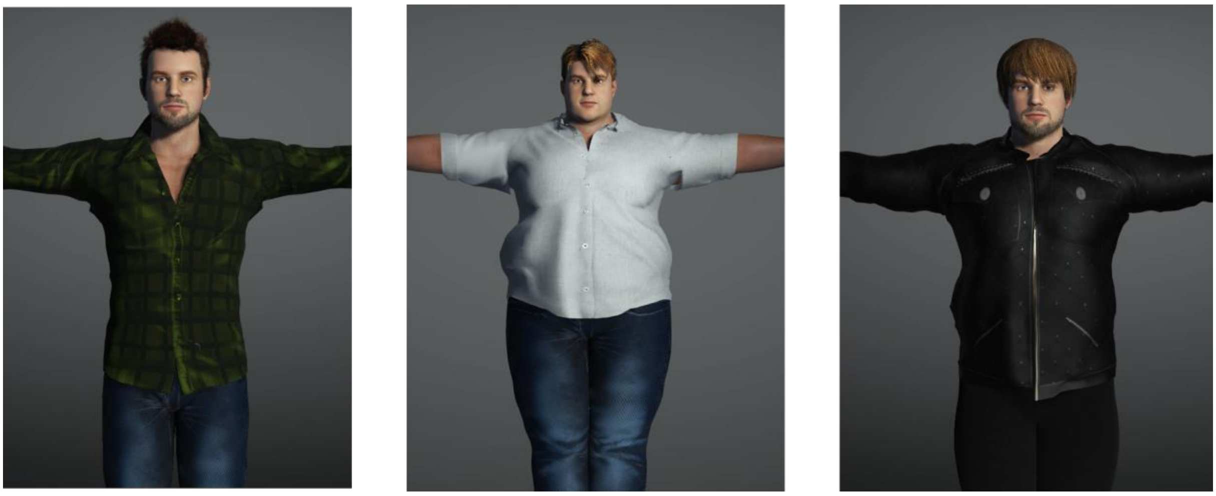

Figure 26. Application examples of various styling and anthropometric parameters to a Base Model

6.1 Base Models: Concept and Characteristics

Fundamentally, the *Base Models* are 3D models saved in `.glb` format and designed to depict all the structural and semantic information necessary for transforming into a VH that accurately represents a given VUM.

Their design ensures adaptability across multiple physical attributes and use cases, while maintaining consistency in proportions, rigging, and visual fidelity.

The key adaptable characteristics of a *Base Model* are summarised below:

- **Height**: The overall scale of a Base Model corresponds directly to the height of the represented individual. Each *Base Model* includes metadata describing its height in real-world centimeters, allowing the model to be scaled proportionally. This guarantees accurate human scaling across simulation environments and ensures coherence when multiple VHs coexist in the same virtual scene.
- **Weight and Muscularity:** Every *Base Model* is designed with a neutral or normal body mass index (BMI) as its default state. To reflect variations in body composition, two blendshape morph targets are implemented:

- **“Weight” blendshape:** Controls overall body mass, allowing the representation of thinner or heavier body types. This parameter accepts values from 0 (minimum body fat) to 1 (maximum body fat). Intermediate values yield smooth, continuous transitions between the two extremes.
- **“Muscular” blendshape:** Adjusts muscle definition and volume, enabling more athletic or toned body representations.

Both morphs coexist and can be combined, allowing nuanced control over body composition (e.g. a heavy yet muscular individual). This dual-blendshape system enables accurate and inclusive visual representations across a spectrum of human physiques (see Figure 27).

Figure 27. A Base Model with different values for weight and muscularity blenshapes

- **Age:** Each *Base Model* includes texture sets corresponding to two age extremes: *youngest* and *oldest*. By blending these textures dynamically, intermediate age appearances can be generated. This approach allows for smooth and realistic representation of age-related skin features such as wrinkles, tone variation, and pigmentation.
- **Skeleton Rigging:** *Base Models* are rigged with a standardized human skeleton. This enables:
  - the injection of animations (walking, sitting, using assistive devices),
  - Compatibility with standard motion capture data, and
  - Dynamic integration into simulation environments. Rigging is essential for ensuring VHs can perform movement-based activities, supporting use cases in ergonomic analysis, accessibility simulation, and motion visualization.
- **Poses:** A comprehensive set of static poses (one-frame animations) is included to visually represent various mobility conditions.
  These poses align with the mobility descriptors defined in the VUM schema, including:
  - Independent (no aid)
  - Wheelchair user
  - Cane user
  - Walking stick user
  - Walking frame user

  Each pose has been carefully constructed to ensure anatomical plausibility and correct alignment between the human model and any assistive device.
- **Walking Aid Models:** In addition to human geometry, each *Base Model* package contains 3D models of all **assistive walking devices** included in the VUM ontology. These assets (e.g., wheelchairs, crutches, walking frames) are:
  - positioned relative to the skeleton rig for natural alignment,
  - included as separate meshes to allow selective activation, and
  - ready to be animated coherently with body motion.
- **Clothing:** *Base Models* include a range of clothing options (shirts, trousers, shoes, outerwear). Each garment contains the same blendshape set as the underlying body, ensuring that changes in weight or muscularity are propagated consistently to the clothing mesh.

This guarantees correct deformation when the body morphs, preserving realism and avoiding geometric interpenetration.

- **Haircuts and Facial Hair:** Different haircuts and, where applicable, facial hair styles are incorporated into each *Base Model*. These assets can be recolored dynamically to enhance diversity and personalization. Each hair asset is also morph-compatible, ensuring correct behavior during facial animation or body morphing.

Two *Base Models* were created for the purposes of the AccesS project (see Figure 28):

- **John**: representing a male body structure,
- **Jane**: representing a female body structure.

Both models include all components described above and serve as the foundational assets for generating a wide range of VHs. Their creation workflow is detailed below.

Figure 28. The two Base Models, Jane (left) and John (right)

6.2 3D Model Format

The *.glb* (GL Transmission Format, binary) was selected as the standard output format for *Base Models* due to its combination of compactness**,** interoperability, and rich feature support. The decision was motivated by the following factors:

- **Industry-wide Adoption:** *.glb* is part of the open glTF 2.0[1] standard developed by the Khronos Group and is supported across major 3D engines (Unity, Unreal, Babylon.js) and web technologies (WebGL, Three.js). This ensures future-proof accessibility and compatibility.
- **Self-contained Structure:** All materials, textures, animations, and blendshapes are embedded in a single file. This eliminates dependency on external assets, reducing management complexity and improving portability.
- **Lightweight and Efficient:** *.glb* offers efficient binary compression, enabling fast loading times. This makes it ideal for both lightweight web applications (e.g. browser-based accessibility tools) and high-detail desktop simulations.
- **Blendshape and Animation Support:** Unlike simpler formats (e.g. OBJ or STL), *.glb* natively supports blendshapes, skeletal animation, and physically based rendering (PBR) materials—key requirements for realistic and dynamic human representation.
- **Alignment with Open Standards and Accessibility**: Its open nature aligns with the European Commission's emphasis on interoperability and sustainability. It supports metadata annotation,

[1] https://registry.khronos.org/glTF/specs/2.0/glTF-2.0.html

enabling future linkage with semantic descriptors of VUMs for automated rendering or personalization.

6.3 Creating a Base Model: A 2-step Workflow

The process of creating the *Base Models* followed a two-step workflow integrating two main tools: Character Creator (for asset generation) and Blender (for final integration, morph definition, and export).

6.3.1 Create realistic / stylized 3D human characters

The first tool employed to the workflow is Character Creator (CC)[2] , a professional-grade tool for building realistic, rigged 3D human models. CC allows control over anthropometric features, facial characteristics, and clothing, while maintaining compatibility with standard 3D pipelines. The Character Creator workflow included the following:

- **Base Body Selection:** The initial human body was chosen from Character Creator's library to serve as the foundation for the Base Model.
- **Clothing Integration:** A range of clothing assets (shirts, trousers, outerwear) were imported and adapted to the model. Since Character Creator allows only one clothing item per layer (e.g. one shirt, one pair of trousers), a procedure was applied where garments were applied and then unlinked to enable simultaneous export of multiple clothing options.
- **Assistive Device Integration:** Walking aid 3D objects (wheelchair, cane, crutches, walking frame) were imported and anchored to the appropriate bones in the skeleton. Correct anchoring ensures realistic alignment and motion when animated.
- **Pose Creation:** The *Create Pose* functionality (Figure 29) was used to generate the different static body positions corresponding to the mobility conditions defined in the corresponding user profile.

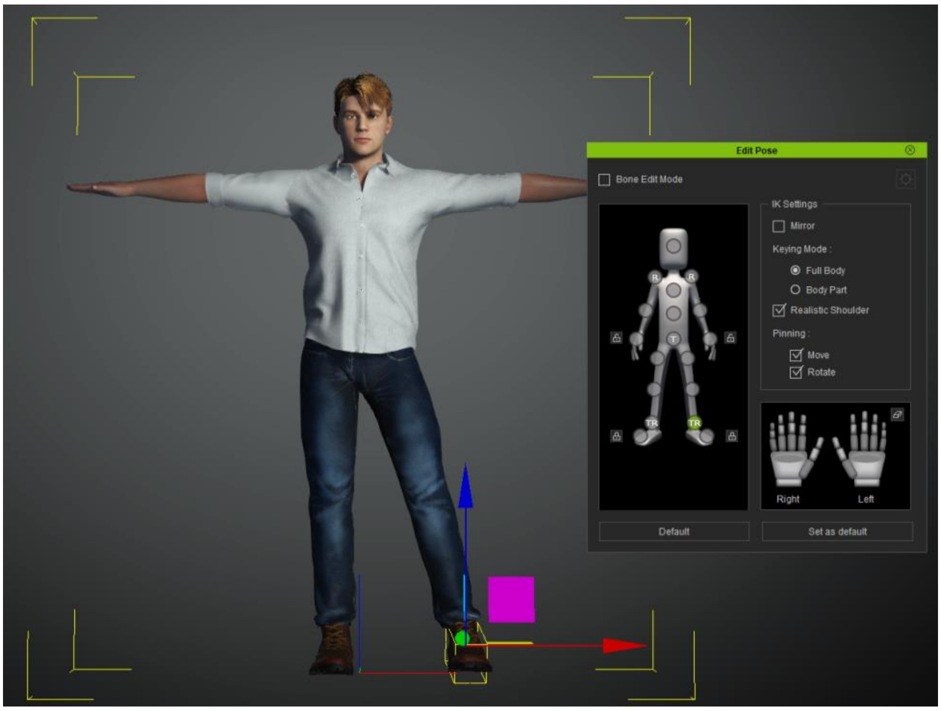

Figure 29. Character Creator's Edit Pose

[2] https://www.reallusion.com/character-creator/

- **Body Shape Variants:** Using CC's Body Morphs (see Figure 30), three separate models were created to represent:
  - a Thin body type,
  - a Muscular body type, and
  - an Overweight body type.

Each variant includes all accessories and clothing elements. As CC does not export body morphs directly, these variations were later combined into a single morphable model in Blender.

Figure 30. Character Creator's Body Morphs

The output of this step consisted of three *.fbx* files containing fully rigged and clothed models for each base model with accessories and poses.

6.3.1 Integration, morph definition, and exporting

Blender[3], an open-source 3D creation suite, was employed to consolidate and refine the assets generated in Character Creator, and to prepare them for export to `.glb`. Although CC excels at creating visual detail, Blender provides the flexibility required to construct and standardize morphs, naming conventions, and hierarchical structures.

The Blender workflow included the following:

- **Import of FBX Models**: The three variants (Thin, Muscular, Overweight) were imported.
- **Blendshape Creation**: Morph targets were created by comparing corresponding geometries across the variants, generating smooth transitions between body shapes. Blendshapes were named uniformly (e.g. `Overweight`, `Muscular`) to ensure programmatic consistency.

[3] https://www.blender.org/

- **Replication of Blendshapes Across Assets**: Each clothing item, haircut, facial hair mesh, and accessory received identical blendshape definitions. This ensured synchronized deformation when the user's body type changes dynamically.
- **Semantic Naming of Meshes:** To facilitate automatic parsing and scripting, all meshes were renamed with intuitive identifiers (e.g. `Wheelchair`, `Haircut_01`, `Shirt_02`, `Shoes_03`). This improves maintainability and enables rule-based generation of VHs from VUM data.

- **Verification of Rigging and Materials**: Skeleton hierarchies and PBR material parameters were verified to ensure compatibility and visual consistency.
- **Export to GLB**: The final model, now containing all blendshapes, rigging, animations, and textures, was exported in `.glb` format as the definitive *Base Model*.

7 VUMs GUI Editor

The Virtual User Models Editor (VUMs Editor) constitutes a key technological component of the AccesS Suite, designed to facilitate the creation, modification, and management of VUMs.

The VUMs Editor provides a user-friendly web interface that bridges the gap between domain experts, designers, and the graph-based database storing the underlying model data. It enables end-users to create and manipulate complex user representations without requiring in-depth technical knowledge of database structures or programming.

Through its functionalities, the VUMs Editor supports the broader goal of the AccesS initiative: to promote accessibility, inclusion, and human-centered design across digital and physical environments.

As part of the project's integration and validation activities, the VUMs Editor has been deployed online and is accessible through the AccesS platform at https://euproject-access-forth.eu/UserModels.

The development of the VUMs Editor addresses several technical and methodological objectives such as:

- **Accessibility and Usability**: To provide a clear, intuitive, and responsive interface for interacting with Virtual User Models, ensuring accessibility for both technical and non-technical users.
- **Data Consistency and Integration**: To ensure seamless communication with the central graph database, enabling real-time data propagation and recalculation of anthropomorphic parameters whenever model properties change.
- **Security and Interoperability**: To implement robust authentication and role-based access control through the integration of Keycloak, in alignment with the project's unified security framework.
- **Scalability and Sustainability**: To employ modern web technologies (such as Next.js) that guarantee high performance, maintainability, and easy future extensions.

By fulfilling these objectives, the VUMs Editor represents a cornerstone for achieving cross-domain interoperability, enabling data-driven user modeling across all AccesS subsystems.

7.1 Technological Stack

For the creation of the VUMs Editor state of the art methods and technologies were utilized for the design process, the developing of the frontend and backend, and user authentication.

7.1.1 Design Process

An iterative design methodology was adopted, enabling continuous feedback and improvement throughout the development process. This approach ensured that the tool evolved in close alignment with user needs and project requirements, improving usability and functionality over time.

7.1.2 Frontend: Next.js

The frontend was developed using Next.js[4]**,** a modern React-based framework known for its efficiency, flexibility, and developer experience. Its main benefits include:

- **Hybrid Rendering**: enabling both real-time and pre-rendered views for optimal performance.
- **Dynamic Routing**: simplifying navigation and user interaction across different VUMs.

[4] https://nextjs.org/

- **Component Reusability**: allowing modular interface design, crucial for scalability.
- **SEO and Performance Optimization**: important for maintaining an accessible public-facing application.

7.1.3 Backend Communication

The frontend communicates with the graph-based backend database via a REST API (described in detail in Section **Error! Reference source not found.**). All operations (create, read, update, delete) are v alidated, version-controlled, and logged to ensure traceability and data integrity. Additionally, the backend performs on-the-fly recalculations of anthropomorphic data based on changes in model parameters, maintaining coherence between derived metrics.

7.1.4 Authentication and Role Management

User authentication and authorization were implemented via Keycloak, an open-source identity management platform adopted across the AccesS ecosystem. This integration ensures:

- Centralized authentication through a single sign-on (SSO) mechanism.
- Encryption and secure session management**.**
- Granular role definitions, distinguishing between administrators, editors, and read-only users.
- Full compliance with General Data Protection Regulation (GDPR) and project-level data protection policies.

7.2 The VUMs Editor User Interface

7.2.1 Homepage

The homepage (see Figure 31) serves as the central dashboard for managing all existing VUMs. The page includes responsive layout elements to support both desktop and mobile use, and its design emphasizes clarity, minimalism, and accessibility.

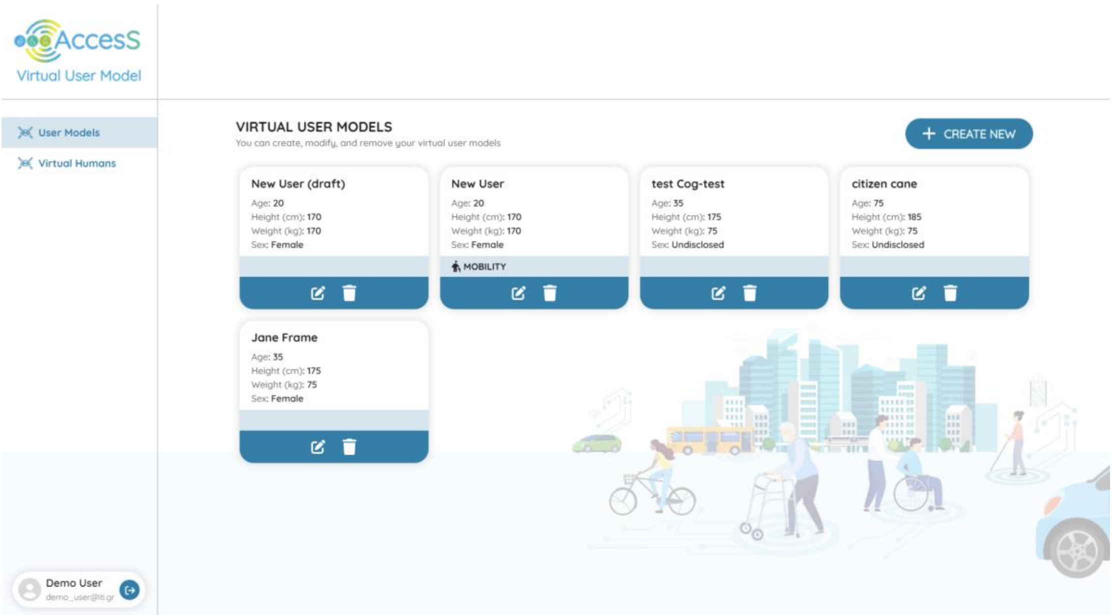

Figure 31. The VUMs Editor Homepage

It displays a series of VUM “cards” (Figure 32.), each summarizing the key properties of a model:

- **General Information**: Some data of the User Model's general information (as it is described in previous sections) is included here, namely unique name, age, height, weight and sex
- **Disability Icons**: These icons denote whether the VUM has any disabilities of the relative category (Mobility, Visual, Hearing).

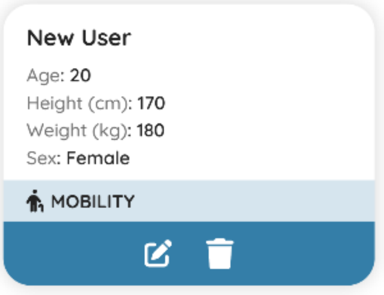

Figure 32. Virtual User Model UI Card

Each card features buttons for editing and deleting the VUM. A "Create New" button is prominently placed to initiate the model creation workflow.

7.2.2 VUM Creation Work Flow

The creation workflow consists of three successive steps as outlined below:

1. Entering General Information
2. Entering Types of Disabilities
3. Fine-Tuning metrics

After each step, the system communicates with the database to propagate data and recalculate dependent parameters, as explained in Subsection 4.2.

7.2.2.1 Step 1: General Information

The first step of the VUM creation workflow focuses on collecting the General Information values, which serve to initialize the model. Figure 33 illustrates a clear and structured form where users are invited to enter key personal characteristics of the virtual user.

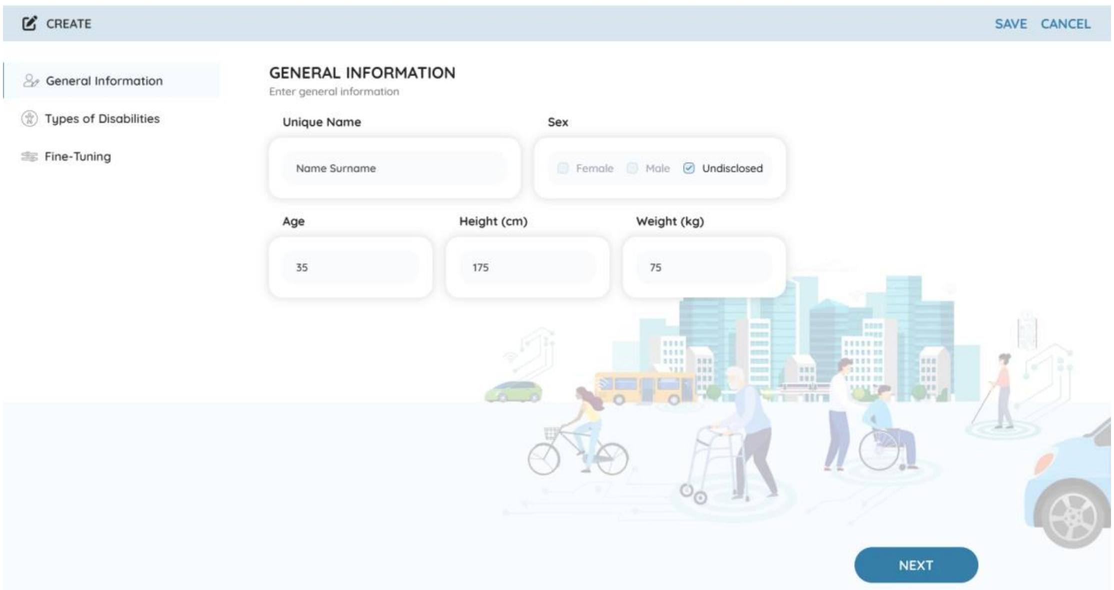

Figure 33. The General Information Page

All fields are validated both on the client and server side to ensure consistency and maintain data integrity. The fields filled in this step are the following:

- **Unique Name**: A combination of name and surname that serves as the primary identifier of the Virtual User Model. The input field accepts alphanumeric characters and symbols, allowing flexible naming conventions that accommodate different languages and organizational standards.
- **Sex**: A mandatory field represented by radio buttons offering three exclusive options, Male, Female, and Undisclosed. This approach ensures both inclusivity and compliance with data protection principles, while providing necessary information for models where sex-specific anthropometric data are relevant.
- **Age**: A numeric field accepting only integer values between 0 and 100. Age directly influences several anthropometric calculations, such as strength estimation and range of motion parameters, and is therefore strictly validated.
- **Height**: The user specifies the height of the virtual person in centimeters, within the range of 0 to 250 cm. This parameter serves as a baseline for proportional scaling of limb lengths and reach distances.
- **Weight**: The body weight, expressed in kilograms, within a valid range of 0 to 300 kg. This value is used to derive biomechanical estimates such as lifting capacity, balance, and joint loadings.

Upon completion of this step, the system stores the entered data temporarily and triggers the first synchronization with the database, generating an initial draft of the VUM, creating it with the default values calculated by its General Information.

7.2.2.2 Step 2: Declaring Disabilities Types

The second step enables users to define any disabilities that characterize the user. Figure 34 depicts a structured list of disability categories that is drawn directly from the semantic database, currently mobility, visual and auditory disabilities. Users can select one or more applicable disabilities by ticking the corresponding options.

Figure 34. The Disabilities page

Once a disability is selected, the system expands to display a set of context-dependent sub-fields (see Figure 35) as is described by the Disabilities entries in the database.

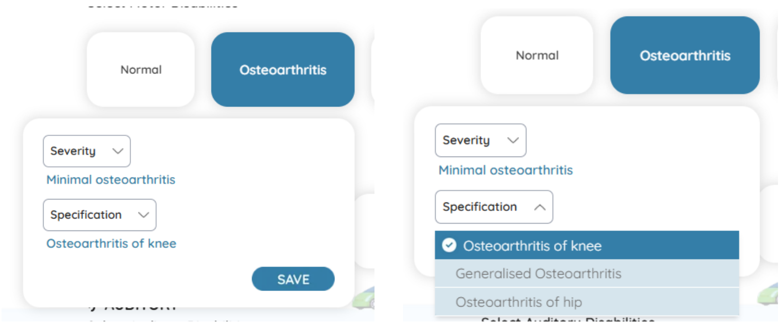

Figure 35. Contextual Information of Disabilities

These may include the categories *Specification*, *Placement* and *Severity*, with each entry in these categories for each Disability taking unique values. These values are loaded dynamically from the database to enable synchronization with the latest VUMRef as described in Chapter 3.

Users can iteratively add or remove disabilities. The interface is fully responsive, ensuring that only relevant fields are visible at any given time, thus reducing cognitive load and avoiding visual clutter.

Once the user completes this configuration, pressing **Next** advances the workflow to the Fine-Tuning stage. At this transition point, the system updates the semantic graph database with the selected disabilities and recalculates all dependent metrics. This ensures that the next stage reflects accurate baseline parameters influenced by the chosen conditions.

7.2.2.3 Step 3: Fine-Tuning

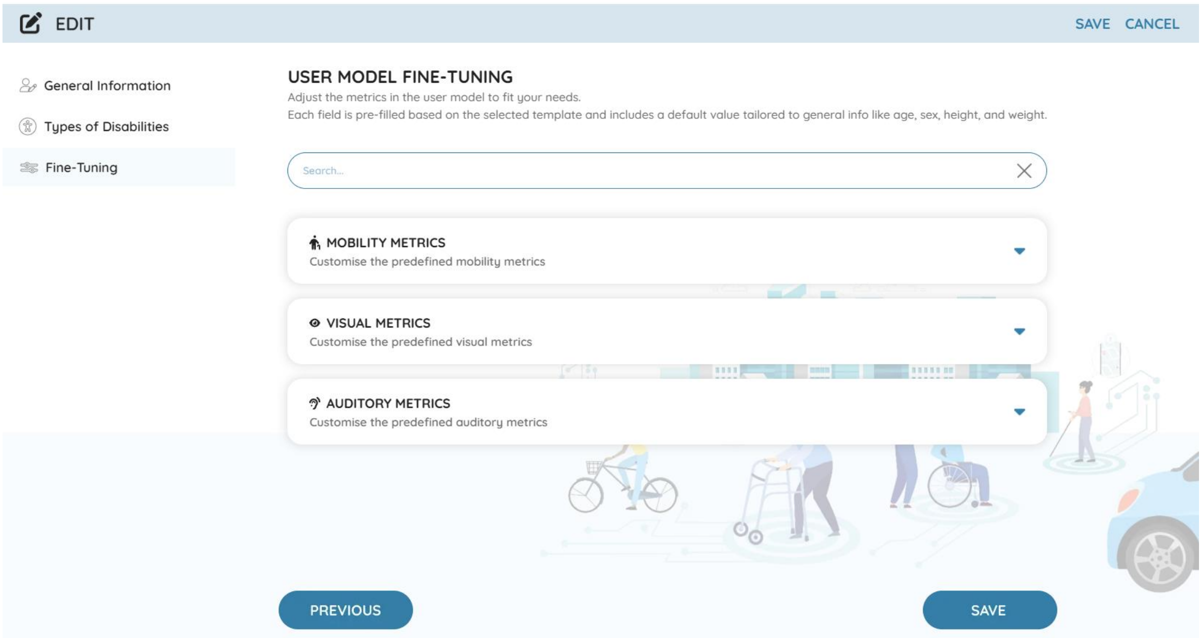

Figure 36. The Fine-Tuning Page

The final step in the VUM creation workflow (see Figure 36) provides users with the ability to potentially refine and customize each metric of the model. This is the most interactive and data-rich phase, allowing expert users to precisely shape the virtual user according to specific physical profiles or study requirements.

Each VUM is initialized with a set of default metrics according to the VUMRef. These metrics define the virtual user's capabilities across several functional domains:

- **Mobility** (e.g., joint range of motion, muscular strength, balance)
- **Visual** (e.g., visual acuity, field of view, color discrimination)
- **Auditory** (e.g., hearing thresholds, directional sensitivity)
- **Cognitive** (e.g. preparation time, initiation time)

Metrics are organized hierarchically into different Metric Groups as seen in Figure 37, enabling intuitive navigation through cascading expandable and collapsible lists. This hierarchical structure mirrors the ontology of the underlying database and supports both broad overviews and detailed adjustments.

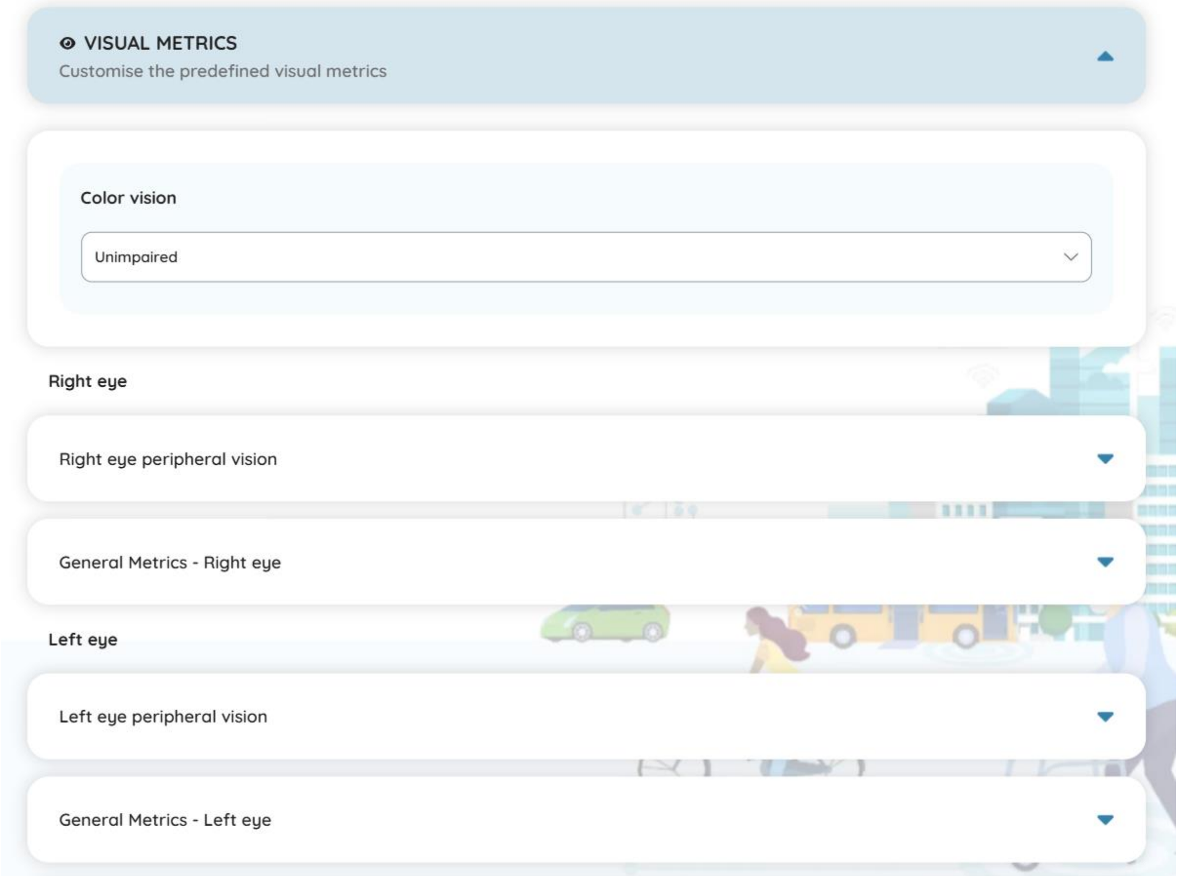

Figure 37. Grouping of Metric in the Fine-Tuning step

Each **Fine-Tuning Metric Interface** displays:

- Metric Name
- Unit of measurement (e.g., °, cm, kg, %)
- Current value
- Minimum and maximum permissible values (if applicable)
- The appropriate control widget for adjustment

The VUMs Editor employs adaptive input components to improve usability as seen in Figure 38:

- Dropdown menus for discrete or categorical metrics (e.g., *Walking Aid* → *None*, *Cane*, *Crutches*, *Wheelchair*)
- Linear sliders for quantitative ranges (e.g., *Grip Strength*, *Reach Distance*)
- Circular sliders for angular parameters (e.g., *Left Shoulder Flexion*, *Knee Extension*)

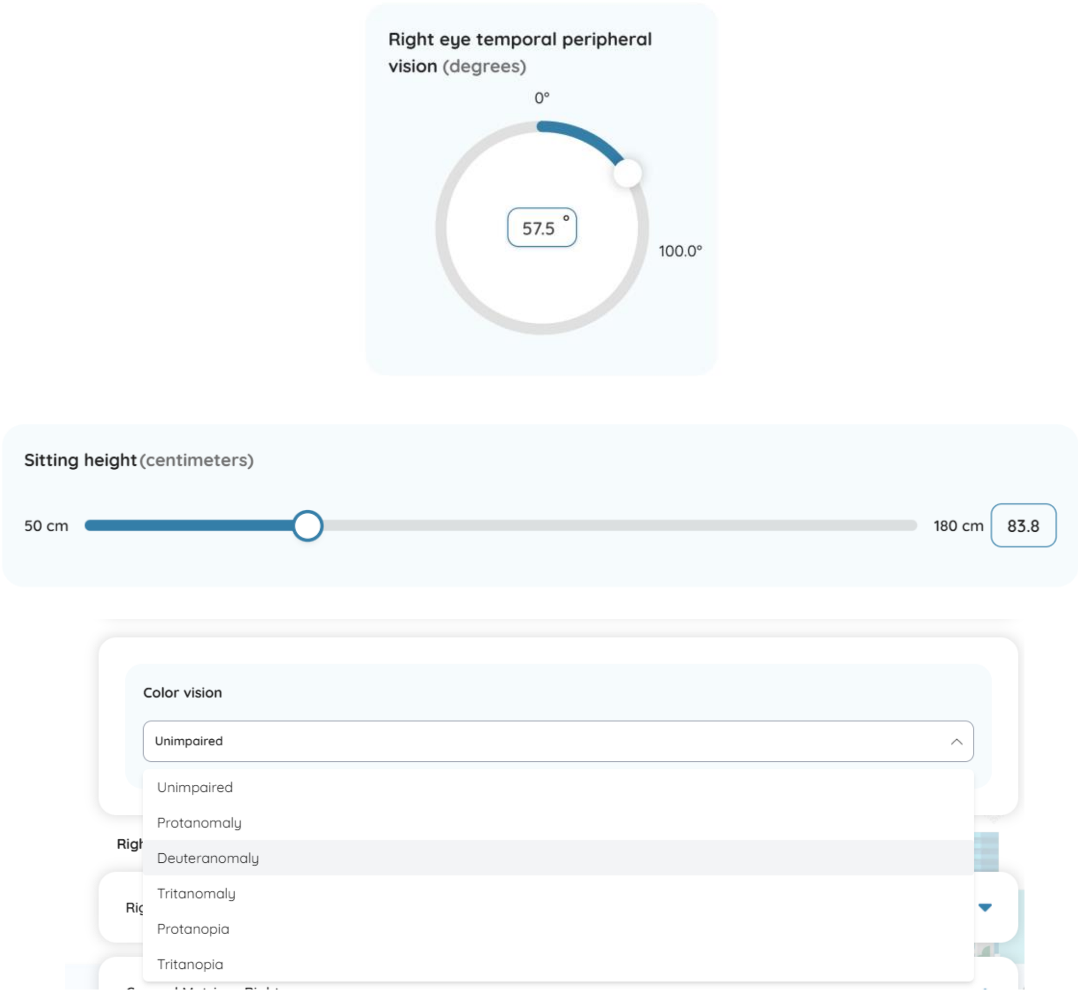

Figure 38. Adaptive Input Components for Metrics

Each input control has been designed to provide a natural and intuitive interaction that aligns with the type of data being modified, thereby reducing user error and making the process approachable even for non-expert users.

Given the large and potentially expanding number of metrics, the interface includes a search mechanism (see Figure 39). Users can type a metric name or a group label and click on the returning results to instantly navigate at the specific spot.

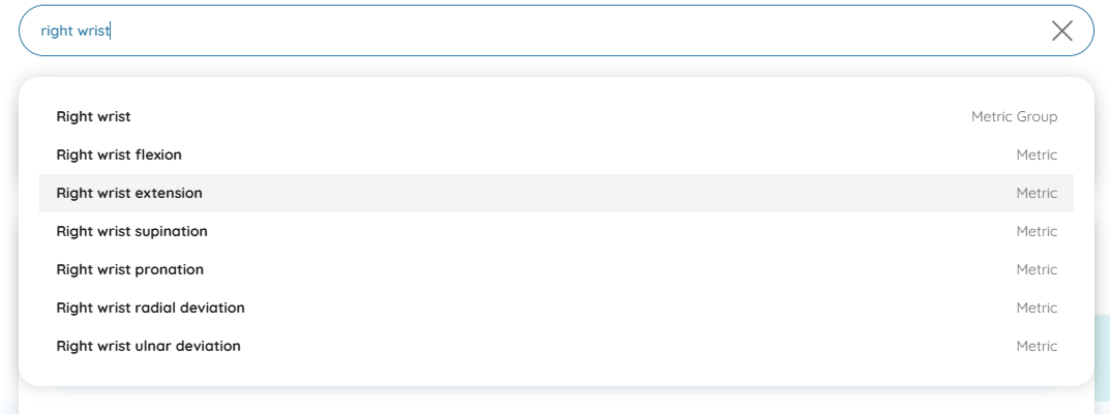

Figure 39. The search functionality in Fine-Tuning

Users can make as many adjustments as needed before finalizing their model by pressing the *Save* button at the bottom-right, which stores the finalized VUM in the graph database and deletes any temporary drafts.

7.2.3 Data Persistence and Draft Mechanism

At any point, users can click Save (top-right corner) to store current progress. Upon completion, the Save and Upload function finalizes the process, triggers recalculation, and updates the graph database. A confirmation dialog verifies successful upload.

After every major modification, the system automatically generates a draft VUM, labeled “(draft)”. This mechanism prevents data loss in cases of accidental closure, network interruptions, or system failures. Drafts are automatically managed according to the following logic:

- A draft is deleted once the finalized version is successfully uploaded.
- Manual saving of a draft overwrites the corresponding original model.
- Cancelling creation deletes associated drafts to maintain database cleanliness.

This approach provides fault tolerance, ensuring a resilient user experience.

7.2.4 VUM Edit Work Flow

The editing process mirrors the creation workflow, providing users with the same structured sequence of steps and identical editing controls. Existing data are preloaded, allowing users to adjust or fine-tune parameters without re-entering basic information. All draft and save mechanisms remain active during the editing process, maintaining data consistency and continuity.

8 VHs GUI Editor

Virtual Humans (VHs), as introduced in previous sections, constitute the 3D visual embodiment of Virtual User Models (VUMs). A VH contains (i) a reference to a VUM and (ii) a fully configured 3D model whose appearance and attributes are shaped according to the VUM's parameters. This linkage is enabled through the use of *Base Models* (see Section 6), which are parametric, morphable 3D models capable of being adapted at runtime to reflect diverse human characteristics and accessibility-related attributes.

Each VH is generated by selecting a *Base Model* and applying the relevant parameters extracted from its corresponding VUM. These parameters include physical attributes (e.g. height, weight, muscularity, age), pose, assistive devices, clothing, and hairstyle. The Virtual Human Editor (VH Editor) provides an intuitive graphical user interface (GUI) that streamlines this process for both expert and non-expert users, focusing on the interactive visual configuration of the VH's 3D representation.

This section presents a comprehensive overview of the design, implementation, and functionality of the VH Editor developed within the AccesS project.

8.1 Authentication and Access Control: Keycloak

Keycloak is integrated for user authentication, identity management, and role-based access control. This ensures secure data access and privacy-preserving workflows throughout the VH creation and editing process.

8.2 3D Rendering Engine: Three.js

The 3D capabilities of the VH Editor rely on the employed 3D Rendering Engine Three.js[5], which is used for:

- loading and rendering *.glb Base Models*,
- displaying and animating 3D geometry,
- handling camera controls and navigation in the 3D view,
- capturing screenshots of the final VH.

Three.js was selected due to several advantages:

- native support for *.glb*/glTF 2.0 including blendshapes, animations, and PBR materials,
- lightweight footprint suitable for browser-based applications,
- JavaScript-based, allowing seamless integration with Node.js and frontend frameworks,
- large community, extensive documentation, and long-term maintainability,
- high performance for real-time rendering even in constrained environments,
- cross-platform and cross-browser compatibility.

This stack ensures that the VH Editor remains responsive, interoperable, and scalable across different use cases.

[5] https://threejs.org/

8.3 Homepage

The homepage of the VH Editor (Figure 40) presents all previously created Virtual Humans in a card-based layout. Each card provides key information to support quick identification and contextual understanding:

- Name of the referenced VUM
- General information extracted from the VUM: age, height, weight, sex
- Disability indicators shown as icons in the card's top-right corner
- A screenshot of the configured 3D model for fast visual recognition

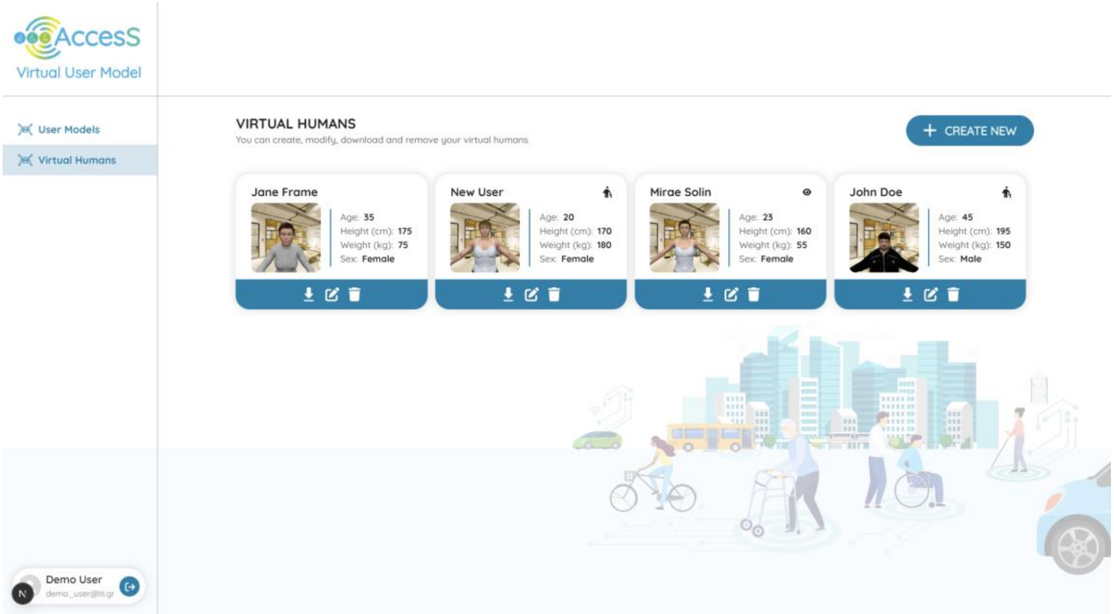

Figure 40. The Homepage of VH GUI

Each card (see Figure 41) also contains three action buttons:

- **Download**: exports the configured VH in .glb format, including geometry, materials, and the selected pose.
- **Edit**: opens the VH Editor workflow with pre-filled settings.
- **Delete**: removes the VH from the system (subject to confirmation).

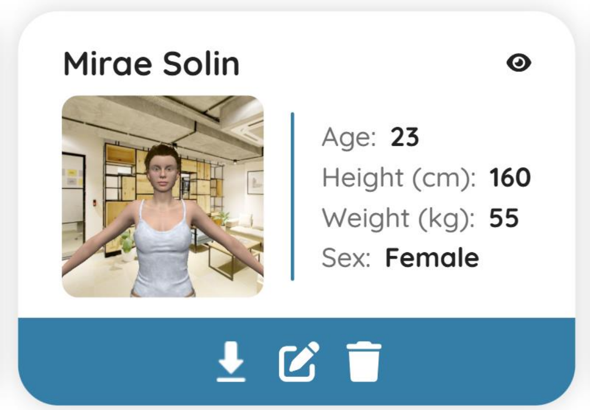

Figure 41. GUI of the Card of Virtual Humans

The VH Editor is hosted in the same web interface as the VUM Editor, under the *Virtual Humans* tab (https://euproject-access-forth.eu/VirtualHumansPage). Consolidating the two tools in a single platform allows users to seamlessly alternate between editing VUMs and creating VHs, supporting efficient workflows and reducing cognitive overhead.

8.4 VH Creation Workflow

Selecting *Create New* initiates a structured creation pipeline consisting of three sequential steps:

1. Selecting the referenced VUM
2. Selecting the Base Model
3. Fine-tuning the 3D model

Each step contributes specific information and constraints, ensuring both flexibility and data integrity.

8.4.1 Step 1: Selecting the referenced VUM

In the first step (see Figure 42) of the VH creation process the user selects the VUM that the new VH will reference. All existing Virtual User Models are displayed as structured cards. Users select the VUM that the new Virtual Human will represent. The card (see Figure 43) provides:

- Full general information of the VUM
- Disability types via clearly identifiable icons
- Any additional contextual information relevant for understanding the user profile

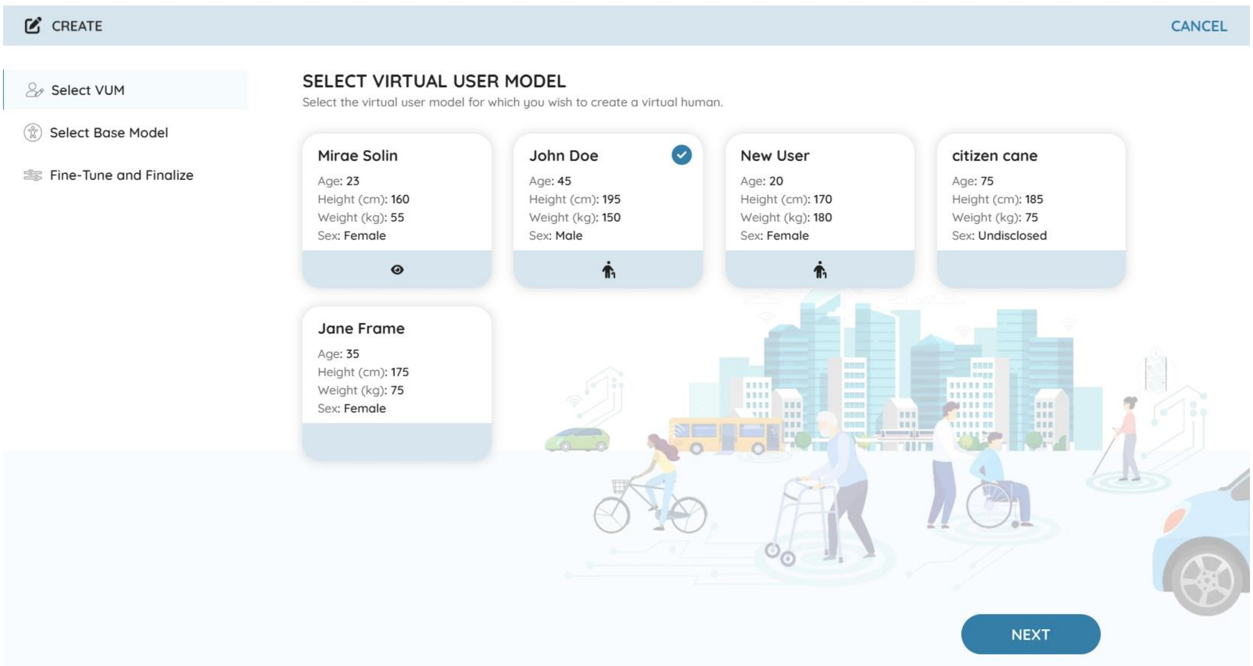

Figure 42. Selecting VUM for a Virtual Human page

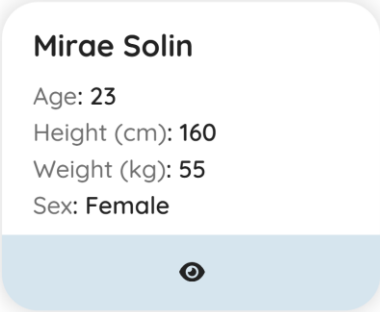

Figure 43. UI Card for VUM in the Select VUM step

Once a VUM is selected, the user proceeds by clicking *Next*. This first step ensures that the Virtual Human inherits key demographic and accessibility parameters from the underlying user profile.

8.4.2 Step 2: Selecting the Base Model

In this step (see Figure 44), users choose a *Base Model* from a display of standardized model cards. Each card includes:

- *Base Model* name
- Default preview image
- Description of the body type

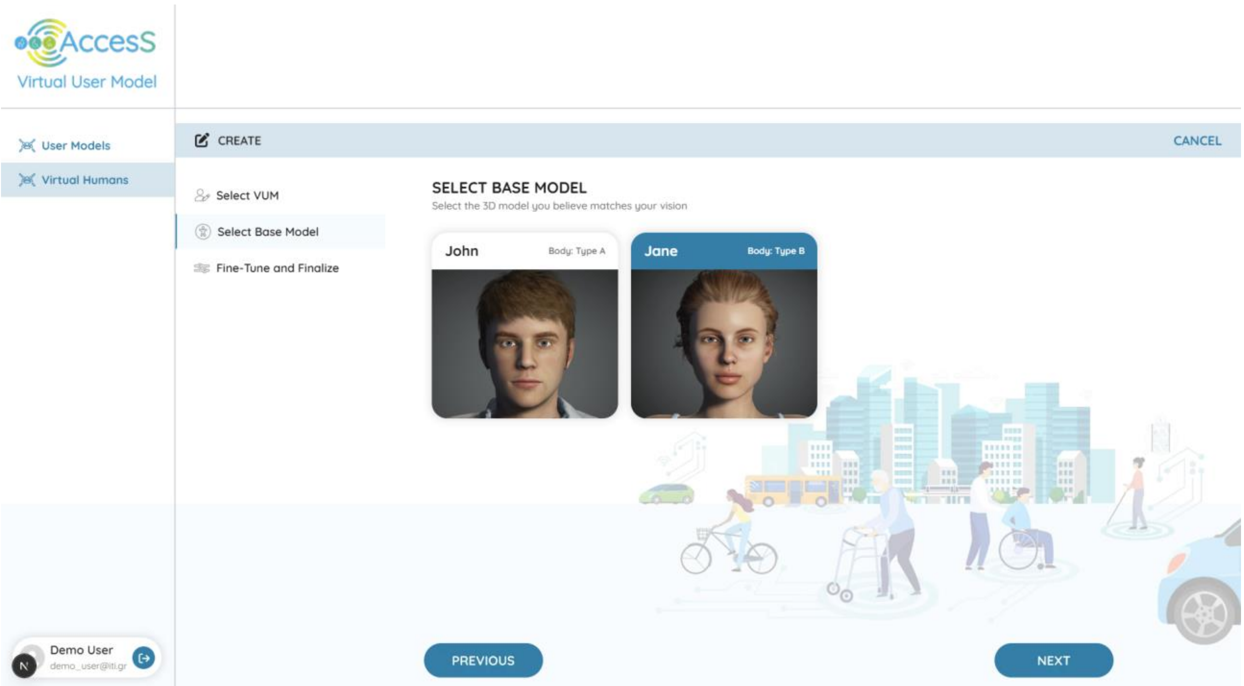

Figure 44. Selecting Base Model page for Virtual Humans

The system distinguishes two body types:

- **Body Type A**: typically corresponding to male anatomical characteristics
- **Body Type B**: typically corresponding to female anatomical characteristics

Importantly, although the VUM contains gender information, the editor does not restrict *Base Model* selection based on gender. This design choice supports inclusivity, accommodates non-disclosed or non-binary gender selections, and avoids enforcing normative mappings between gender and body type.

After selecting the *Base Model*, the user proceeds to the final configuration step via the *Next* button.

8.4.3 Step 3: Fine Tuning the Model

The third step (see Figure 45) provides a detailed interface for customizing the visual appearance of the Virtual Human. Upon entering this step, the system automatically applies all VUM-driven parameters to the Base Model, including:

- Weight and height
- Age-related morphological variations (see Figure 46)
- Pose and posture
- Presence of mobility aids (e.g., walking sticks, wheelchairs, accessories)

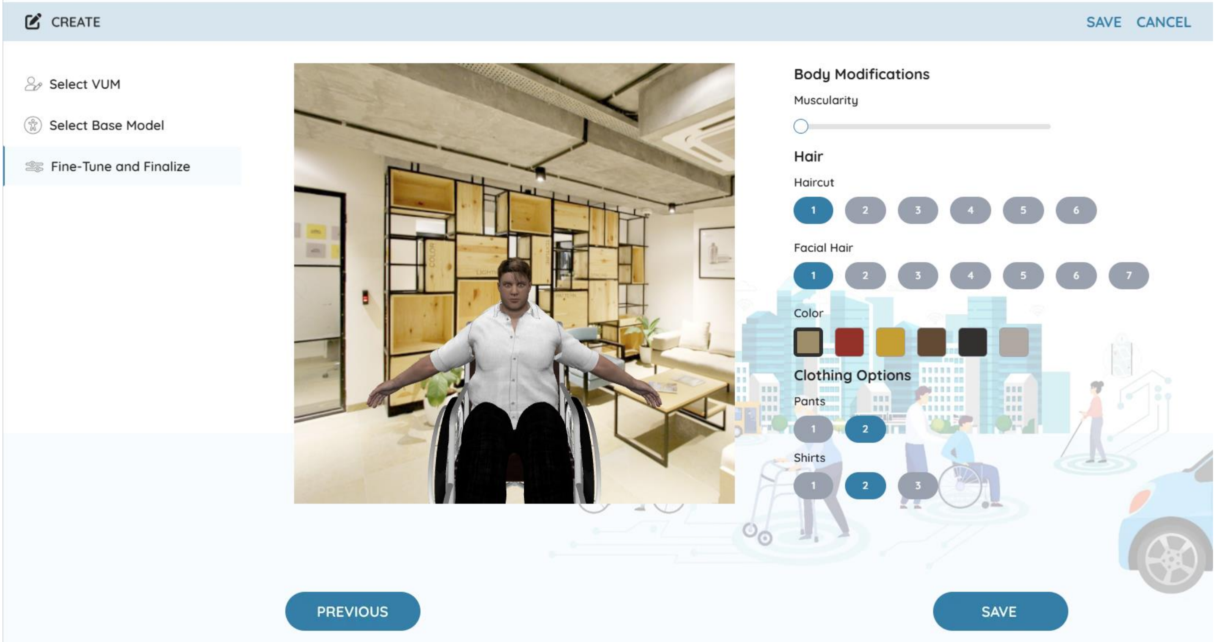

Figure 45. Fine Tuning Model page for Virtual Humans

Figure 46. Aging differences for base model John: Left, 22 years old. Right: 70 years old.

These adjustments form the baseline from which purely cosmetic changes may be applied. All visual changes are applied in real time in the Three.js viewer.

Cosmetic options are grouped into structured categories for usability and scalability:

- **Body Modifications:** Includes a muscularity slider. A computation maps the slider value to the correct blendshape intensities across all relevant meshes.
- **Hair:** For hair the different options are split in two sub-categories, Hair (see Figure 47) and Facial Hair (see Figure 48).

Styles are presented numerically, and users can switch through them interactively. A collection of Hair and facial hair colors is also available for selection.

- **Clothing Options:** Users can select individual clothing layers - such as tops, bottoms, shoes - to combine different outfits. This modular approach enables mixing and matching of styles.

Figure 47. Different Hairstyle options for Base Model John

Figure 48. Different Facial Hair options for Base Model John

The combination of *Base Model* variability, VUM-driven parameters, and fine-tuning styling options ensures that the platform can generate highly individualized Virtual Humans that faithfully represent diverse user profiles (see Figure 49).

Figure 49. Some different Virtual Human 3D models on the VH GUI Editor

8.5 VH Editing Flow

The editing workflow mirrors the creation workflow but begins with all fields pre-populated using the existing VH's data. It also incorporates robust data integrity safeguards to prevent unintended inconsistencies, and various warning and data integrity checks:

- **VUM Changes:** If the referenced VUM has been modified since the VH was created, the dashboard and the VUM-selection step display warnings (see Figure 50). Continuing with the editing process acknowledges that the 3D model may be altered to match the updated data (see Figure 51 – Top Right).

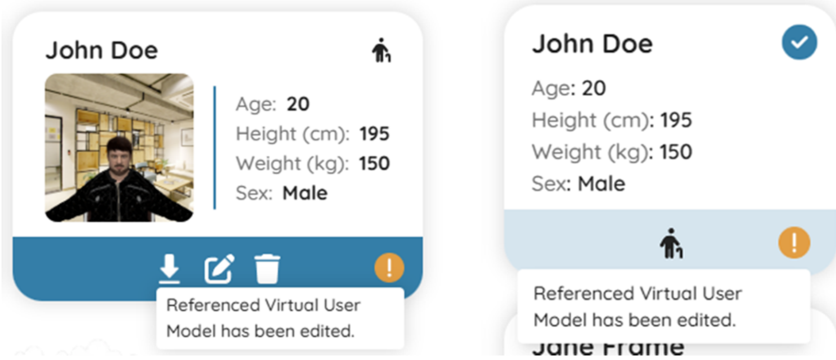

Figure 50. Virtual Human card warnings for VUM change

- **VUM Replacement:** Editing or replacing the referenced VUM can dramatically alter the VH's morphology. The editor displays a high-visibility warning before allowing the change (see Figure 50).
- **Base Model Change:** Because *Base Models* differ significantly (geometry, blendshapes, compatible clothing items), changing the Base Model triggers a warning informing (Figure 51 – Bottom Left) the user that:
    - clothing choices
    - hairstyle selections
    - colours
    - muscularity settings

  will be reset.
- **Deleting a VUM:** As VHs depend on an underlying VUM, deleting that VUM has cascading consequences. Before deletion, the system shows a critical warning informing the user that all dependent Virtual Humans will be affected (see Figure 51 – Bottom Right).

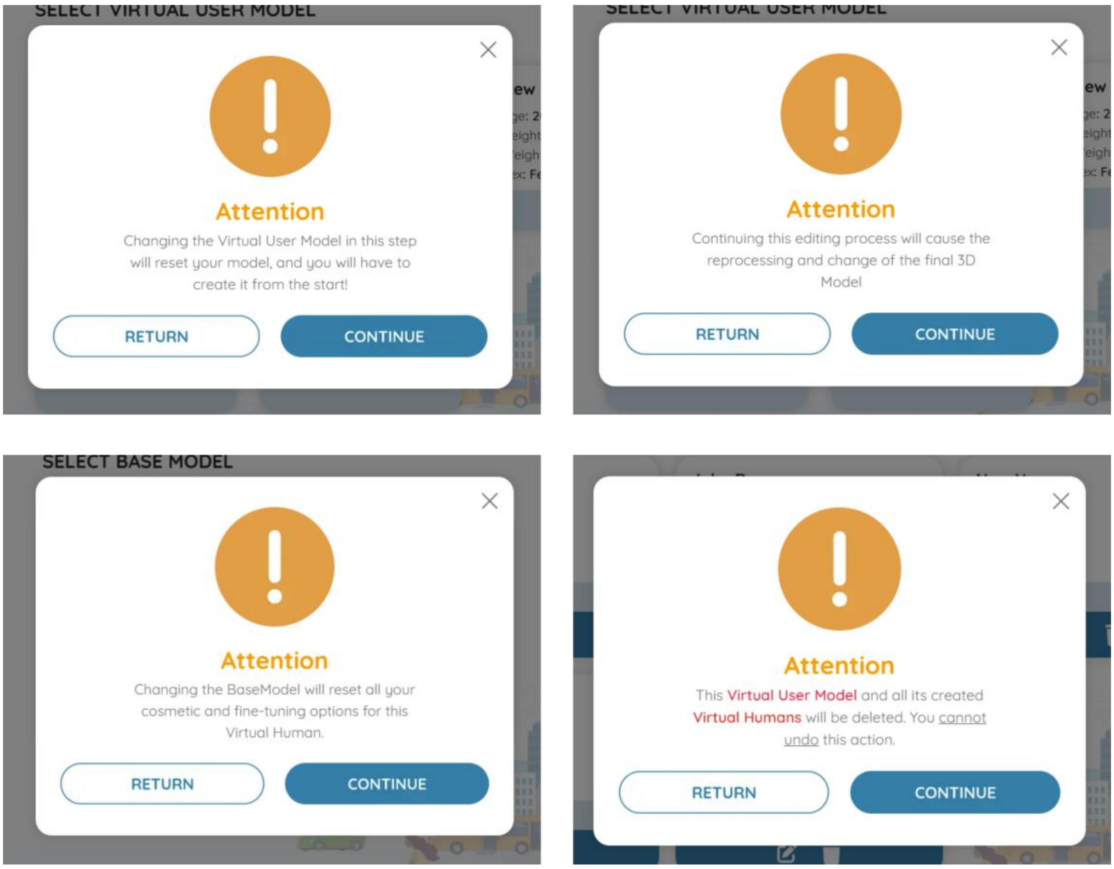

Figure 51. Warnings for data integrity of VHs: Top-left – Attempt to change VUM. Top-Right – Pressing *Next* button after changing VUM. Bottom-Left – Attempt to change Base Model. Bottom-Right – Attempt to delete VUM.

These mechanisms ensure the coherence of the VH - VUM relationship and prevent accidental data loss or model corruption.

9 Conclusions

The work presented herein outlines the first iteration of the Virtual Users Model Reference, and the AccesS Disabilities Reference, a combined effort to facilitate the accessibility assessment of built environments through formalization of human capabilities and the interactions of virtual users with their surroundings.

Further improvement of the models presented must be at the forefront of future goals, after careful examination of initial results from simulated cases. In addition to the refinement of the existing fields of Visual, Mobility and Auditory information currently covered by VUMRef, there is still progress to be done in order to fully represent the full range of an individual's abilities and limitations, namely the fields of Cognitive and Verbal information.

In conjunction with the aforementioned adjustments, the scope of ADRef can similarly be expanded to include disabilities affecting different components of human functionality. The formalization of other conditions impacting the lives of people globally, such as Parkinson's Disease, stroke, and cardiopathy would allow for a universal approach to architectural and constructional design, especially in those cases where one form of disability affects multiple aspects of a person's capability.

10 References

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ANNEX A: Mirae Solin’s User Profile

The User Profile of Mirae Solin is presented below in JSON format.


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{
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                    "value": 108.47,
                    "minimum": 0
                },
                "Left_arm_standing_push_strength__up_": {
                    "unit_of_measurement": "Newtons",
                    "maximum": 0,
                    "tag": "Left arm standing push strength (up)",
                    "value": 250.73,
                    "minimum": 0
                },
                "Left_arm_standing_pull_strength__up_": {
                    "unit_of_measurement": "Newtons",
                    "maximum": 0,
                    "tag": "Left arm standing pull strength (up)",
                    "value": 396.98,
                    "minimum": 0
                }
            },
            "Left_shoulder": {
                "tag": "Left shoulder",
                "Left_shoulder_flexion": {
```

```
                "unit_of_measurement": "degrees",
                "maximum": 190,
                "tag": "Left shoulder flexion",
                "value": 183.5,
                "minimum": 0
            },
            "Left_shoulder_external_rotation": {
                "unit_of_measurement": "degrees",
                "maximum": 90,
                "tag": "Left shoulder external rotation",
                "value": 90,
                "minimum": 0
            },
            "Left_shoulder_abduction": {
                "unit_of_measurement": "degrees",
                "maximum": 155,
                "tag": "Left shoulder abduction",
                "value": 155,
                "minimum": 0
            },
            "Left_shoulder_extension": {
                "unit_of_measurement": "degrees",
                "maximum": 65,
                "tag": "Left shoulder extension",
                "value": 65,
                "minimum": 0
            },
            "Left_shoulder_internal_rotation": {
                "unit_of_measurement": "degrees",
                "maximum": 70,
                "tag": "Left shoulder internal rotation",
                "value": 70,
                "minimum": 0
            },
            "Left_shoulder_adduction": {
                "unit_of_measurement": "degrees",
                "maximum": 40,
                "tag": "Left shoulder adduction",
                "value": 40,
                "minimum": 0
            }
        },
        "Left_elbow": {
            "tag": "Left elbow",
            "Left_elbow_pronation": {
                "unit_of_measurement": "degrees",
                "maximum": 85,
                "tag": "Left elbow pronation",
                "value": 84,
                "minimum": 0
            },
            "Left_elbow_extension": {
                "unit_of_measurement": "degrees",
                "maximum": 10,
                "tag": "Left elbow extension",
                "value": 0,
                "minimum": 0
            },
            "Left_elbow_supination": {
                "unit_of_measurement": "degrees",
                "maximum": 90,
                "tag": "Left elbow supination",
                "value": 89.5,
                "minimum": 0
            },
            "Left_elbow_flexion": {
```

```
                    "unit_of_measurement": "degrees",
                    "maximum": 150,
                    "tag": "Left elbow flexion",
                    "value": 148.75,
                    "minimum": 0
                }
            }
        },
        "Right_arm": {
            "tag": "Right arm",
            "Right_wrist": {
                "tag": "Right wrist",
                "Right_wrist_flexion": {
                    "unit_of_measurement": "degrees",
                    "maximum": 75,
                    "tag": "Right wrist flexion",
                    "value": 74.25,
                    "minimum": 0
                },
                "Right_wrist_extension": {
                    "unit_of_measurement": "degrees",
                    "maximum": 70,
                    "tag": "Right wrist extension",
                    "value": 69.325,
                    "minimum": 0
                },
                "Right_wrist_supination": {
                    "unit_of_measurement": "degrees",
                    "maximum": 85,
                    "tag": "Right wrist supination",
                    "value": 80,
                    "minimum": 0
                },
                "Right_wrist_pronation": {
                    "unit_of_measurement": "degrees",
                    "maximum": 80,
                    "tag": "Right wrist pronation",
                    "value": 75,
                    "minimum": 0
                },
                "Right_wrist_radial_deviation": {
                    "unit_of_measurement": "degrees",
                    "maximum": 20,
                    "tag": "Right wrist radial deviation",
                    "value": 23,
                    "minimum": 0
                },
                "Right_wrist_ulnar_deviation": {
                    "unit_of_measurement": "degrees",
                    "maximum": 50,
                    "tag": "Right wrist ulnar deviation",
                    "value": 48.85,
                    "minimum": 0
                }
            },
            "Right_shoulder": {
                "tag": "Right shoulder",
                "Right_shoulder_flexion": {
                    "unit_of_measurement": "degrees",
                    "maximum": 190,
                    "tag": "Right shoulder flexion",
                    "value": 183.5,
                    "minimum": 0
                },
                "Right_shoulder_external_rotation": {
                    "unit_of_measurement": "degrees",
```

```
                    "maximum": 90,
                    "tag": "Right shoulder external rotation",
                    "value": 90,
                    "minimum": 0
                },
                "Right_shoulder_adduction": {
                    "unit_of_measurement": "degrees",
                    "maximum": 40,
                    "tag": "Right shoulder adduction",
                    "value": 40,
                    "minimum": 0
                },
                "Right_shoulder_internal_rotation": {
                    "unit_of_measurement": "degrees",
                    "maximum": 55,
                    "tag": "Right shoulder internal rotation",
                    "value": 70,
                    "minimum": 0
                },
                "Right_shoulder_extension": {
                    "unit_of_measurement": "degrees",
                    "maximum": 65,
                    "tag": "Right shoulder extension",
                    "value": 65,
                    "minimum": 0
                },
                "Right_shoulder_abduction": {
                    "unit_of_measurement": "degrees",
                    "maximum": 150,
                    "tag": "Right shoulder abduction",
                    "value": 155,
                    "minimum": 0
                }
            },
            "Right_arm_strength": {
                "tag": "Right arm strength",
                "Right_arm_sitting_pull_strength__front_": {
                    "unit_of_measurement": "Newtons",
                    "maximum": 0,
                    "tag": "Right arm sitting pull strength (front)",
                    "value": 198.58,
                    "minimum": 0
                },
                "Right_arm_standing_pull_strength__up_": {
                    "unit_of_measurement": "Newtons",
                    "maximum": 0,
                    "tag": "Right arm standing pull strength (up)",
                    "value": 396.98,
                    "minimum": 0
                },
                "Right_arm_sitting_push_strength__up_": {
                    "unit_of_measurement": "Newtons",
                    "maximum": 0,
                    "tag": "Right arm sitting push strength (up)",
                    "value": 227.04,
                    "minimum": 0
                },
                "Right_arm_grip_strength": {
                    "unit_of_measurement": "Newtons",
                    "maximum": 0,
                    "tag": "Right arm grip strength",
                    "value": 287.52227839999983,
                    "minimum": 0
                },
                "Right_arm_sitting_pull_strength__up_": {
                    "unit_of_measurement": "Newtons",
```

```
                    "maximum": 0,
                    "tag": "Right arm sitting pull strength (up)",
                    "value": 327.38,
                    "minimum": 0
                },
                "Right_arm_key_pinch_strength": {
                    "unit_of_measurement": "Newtons",
                    "maximum": 0,
                    "tag": "Right arm key pinch strength",
                    "value": 63.25490124799996,
                    "minimum": 0
                },
                "Right_arm_sitting_push_strength__front_": {
                    "unit_of_measurement": "Newtons",
                    "maximum": 0,
                    "tag": "Right arm sitting push strength (front)",
                    "value": 124.88,
                    "minimum": 0
                },
                "Right_arm_pulp_pinch_strength": {
                    "unit_of_measurement": "Newtons",
                    "maximum": 0,
                    "tag": "Right arm pulp pinch strength",
                    "value": 46.00356454399997,
                    "minimum": 0
                },
                "Right_arm_standing_push_strength__front_": {
                    "unit_of_measurement": "Newtons",
                    "maximum": 0,
                    "tag": "Right arm standing push strength (front)",
                    "value": 89.39,
                    "minimum": 0
                },
                "Right_arm_standing_push_strength__up_": {
                    "unit_of_measurement": "Newtons",
                    "maximum": 0,
                    "tag": "Right arm standing push strength (up)",
                    "value": 250.73,
                    "minimum": 0
                },
                "Right_arm_standing_pull_strength__front_": {
                    "unit_of_measurement": "Newtons",
                    "maximum": 0,
                    "tag": "Right arm standing pull strength (front)",
                    "value": 108.47,
                    "minimum": 0
                }
            },
            "Right_elbow": {
                "tag": "Right elbow",
                "Right_elbow_flexion": {
                    "unit_of_measurement": "degrees",
                    "maximum": 150,
                    "tag": "Right elbow flexion",
                    "value": 148.75,
                    "minimum": 0
                },
                "Right_elbow_extension": {
                    "unit_of_measurement": "degrees",
                    "maximum": 10,
                    "tag": "Right elbow extension",
                    "value": 0,
                    "minimum": 0
                },
                "Right_elbow_supination": {
                    "unit_of_measurement": "degrees",
```

```
                    "maximum": 90,
                    "tag": "Right elbow supination",
                    "value": 89.5,
                    "minimum": 0
                },
                "Right_elbow_pronation": {
                    "unit_of_measurement": "degrees",
                    "maximum": 85,
                    "tag": "Right elbow pronation",
                    "value": 84,
                    "minimum": 0
                }
            }
        },
        "Pull_strength": {
            "unit_of_measurement": "Newtons",
            "maximum": 1000,
            "tag": "Pull strength",
            "value": 245.46,
            "minimum": 0
        },
        "Horizontal_reach": {
            "unit_of_measurement": "centimeters",
            "maximum": 100,
            "tag": "Horizontal reach",
            "value": 61.5,
            "minimum": 0
        }
    },
    "Sitting_height": {
        "unit_of_measurement": "centimeters",
        "maximum": 180,
        "tag": "Sitting height",
        "value": 92.5,
        "minimum": 50,
    },
    "Lower_body_mobility": {
        "tag": "Lower body mobility",
        "Right_leg": {
            "tag": "Right leg",
            "Right_hip": {
                "tag": "Right hip",
                "Right_hip_internal_rotation": {
                    "unit_of_measurement": "degrees",
                    "maximum": 35,
                    "tag": "Right hip internal rotation",
                    "value": 35,
                    "minimum": 0
                },
                "Right_hip_abduction": {
                    "unit_of_measurement": "degrees",
                    "maximum": 45,
                    "tag": "Right hip abduction",
                    "value": 45,
                    "minimum": 0
                },
                "Right_hip_adduction": {
                    "unit_of_measurement": "degrees",
                    "maximum": 20,
                    "tag": "Right hip adduction",
                    "value": 20,
                    "minimum": 0
                },
                "Right_hip_flexion": {
                    "unit_of_measurement": "degrees",
                    "maximum": 120,
```

```
                "tag": "Right hip flexion",
                "value": 120,
                "minimum": 0
            },
            "Right_hip_external_rotation": {
                "unit_of_measurement": "degrees",
                "maximum": 35,
                "tag": "Right hip external rotation",
                "value": 35,
                "minimum": 0
            },
            "Right_hip_extension": {
                "unit_of_measurement": "degrees",
                "maximum": 20,
                "tag": "Right hip extension",
                "value": 20,
                "minimum": 0
            }
        },
        "Right_leg_step_length": {
            "unit_of_measurement": "centimeters",
            "maximum": 80,
            "tag": "Right leg step length",
            "value": 67,
            "minimum": 5
        },
        "Right_ankle": {
            "tag": "Right ankle",
            "Right_ankle_pronation": {
                "unit_of_measurement": "degrees",
                "maximum": 45,
                "tag": "Right ankle pronation",
                "value": 32.9,
                "minimum": 0
            },
            "Right_ankle_supination": {
                "unit_of_measurement": "degrees",
                "maximum": 45,
                "tag": "Right ankle supination",
                "value": 30.8,
                "minimum": 0
            },
            "Right_ankle_extension": {
                "unit_of_measurement": "degrees",
                "maximum": 45,
                "tag": "Right ankle extension",
                "value": 62.1,
                "minimum": 0
            },
            "Right_ankle_flexion": {
                "unit_of_measurement": "degrees",
                "maximum": 25,
                "tag": "Right ankle flexion",
                "value": 13.8,
                "minimum": 0
            }
        },
        "Right_knee": {
            "tag": "Right knee",
            "Right_knee_flexion": {
                "unit_of_measurement": "degrees",
                "maximum": 140,
                "tag": "Right knee flexion",
                "value": 140,
                "minimum": 0
            },
```

```
                    "Right_knee_extension": {
                        "unit_of_measurement": "degrees",
                        "maximum": 10,
                        "tag": "Right knee extension",
                        "value": 0,
                        "minimum": 0
                    }
                }
            },
            "Walking_cadence": {
                "unit_of_measurement": "steps/minute",
                "maximum": 130,
                "tag": "Walking cadence",
                "value": 107.43,
                "minimum": 10
            },
            "Left_leg": {
                "tag": "Left leg",
                "Left_hip": {
                    "tag": "Left hip",
                    "Left_hip_internal_rotation": {
                        "unit_of_measurement": "degrees",
                        "maximum": 35,
                        "tag": "Left hip internal rotation",
                        "value": 35,
                        "minimum": 0
                    },
                    "Left_hip_extension": {
                        "unit_of_measurement": "degrees",
                        "maximum": 20,
                        "tag": "Left hip extension",
                        "value": 20,
                        "minimum": 0
                    },
                    "Left_hip_flexion": {
                        "unit_of_measurement": "degrees",
                        "maximum": 120,
                        "tag": "Left hip flexion",
                        "value": 120,
                        "minimum": 0
                    },
                    "Left_hip_external_rotation": {
                        "unit_of_measurement": "degrees",
                        "maximum": 35,
                        "tag": "Left hip external rotation",
                        "value": 35,
                        "minimum": 0
                    },
                    "Left_hip_abduction": {
                        "unit_of_measurement": "degrees",
                        "maximum": 45,
                        "tag": "Left hip abduction",
                        "value": 45,
                        "minimum": 0
                    },
                    "Left_hip_adduction": {
                        "unit_of_measurement": "degrees",
                        "maximum": 20,
                        "tag": "Left hip adduction",
                        "value": 20,
                        "minimum": 0
                    }
                },
                "Left_ankle": {
                    "tag": "Left ankle",
                    "Left_ankle_flexion": {
```

```
                    "unit_of_measurement": "degrees",
                    "maximum": 25,
                    "tag": "Left ankle flexion",
                    "value": 13.8,
                    "minimum": 0
                },
                "Left_ankle_pronation": {
                    "unit_of_measurement": "degrees",
                    "maximum": 35,
                    "tag": "Left ankle pronation",
                    "value": 32.9,
                    "minimum": 0
                },
                "Left_ankle_extension": {
                    "unit_of_measurement": "degrees",
                    "maximum": 65,
                    "tag": "Left ankle extension",
                    "value": 62.1,
                    "minimum": 0
                },
                "Left_ankle_supination": {
                    "unit_of_measurement": "degrees",
                    "maximum": 35,
                    "tag": "Left ankle supination",
                    "value": 30.8,
                    "minimum": 0
                }
            },
            "Left_leg_step_length": {
                "unit_of_measurement": "centimeters",
                "maximum": 80,
                "tag": "Left leg step length",
                "value": 67,
                "minimum": 5
            },
            "Left_knee": {
                "tag": "Left knee",
                "Left_knee_extension": {
                    "unit_of_measurement": "degrees",
                    "maximum": 10,
                    "tag": "Left knee extension",
                    "value": 0,
                    "minimum": 0
                },
                "Left_knee_flexion": {
                    "unit_of_measurement": "degrees",
                    "maximum": 140,
                    "tag": "Left knee flexion",
                    "value": 140,
                    "minimum": 0
                }
            }
        },
        "Walking_speed": {
            "unit_of_measurement": "meters/second",
            "maximum": 1.5,
            "tag": "Walking speed",
            "value": 1.18,
            "minimum": 0.05
        },
        "Stair_climbing_speed": {
            "unit_of_measurement": "meters/second",
            "maximum": 1.2,
            "tag": "Stair climbing speed",
            "value": 0.6,
            "minimum": 0.02
```

```
            }
        },
        "Hip_height": {
            "unit_of_measurement": "centimeters",
            "maximum": 150,
            "tag": "Hip height",
            "value": 90.5,
            "minimum": 50
        }
    },
    "Auditory_Information": {
        "tag": "Auditory Information",
        "Right_ear": {
            "tag": "Right ear",
            "Right_ear_8000_Hz_hearing_threshold": {
                "unit_of_measurement": "",
                "maximum": 120,
                "tag": "Right ear 8000 Hz hearing threshold",
                "value": 8,
                "minimum": 0
            },
            "Right_ear_1000_Hz_hearing_threshold": {
                "unit_of_measurement": "",
                "maximum": 120,
                "tag": "Right ear 1000 Hz hearing threshold",
                "value": 9,
                "minimum": 0
            },
            "Right_ear_2000_Hz_hearing_threshold": {
                "unit_of_measurement": "",
                "maximum": 120,
                "tag": "Right ear 2000 Hz hearing threshold",
                "value": 7.5,
                "minimum": 0
            },
            "Right_ear_250_Hz_hearing_threshold": {
                "unit_of_measurement": "",
                "maximum": 120,
                "tag": "Right ear 250 Hz hearing threshold",
                "value": 11,
                "minimum": 0
            },
            "Right_ear_4000_Hz_hearing_threshold": {
                "unit_of_measurement": "",
                "maximum": 120,
                "tag": "Right ear 4000 Hz hearing threshold",
                "value": 5,
                "minimum": 0
            },
            "Right_ear_500_Hz_hearing_threshold": {
                "unit_of_measurement": "",
                "maximum": 120,
                "tag": "Right ear 500 Hz hearing threshold",
                "value": 9,
                "minimum": 0
            }
        },
        "Left_ear": {
            "tag": "Left ear",
            "Left_ear_250_Hz_hearing_threshold": {
                "unit_of_measurement": "",
                "maximum": 120,
                "tag": "Left ear 250 Hz hearing threshold",
                "value": 11,
                "minimum": 0
            },
```

```
            "Left_ear_500_Hz_hearing_threshold": {
                "unit_of_measurement": "",
                "maximum": 120,
                "tag": "Left ear 500 Hz hearing threshold",
                "value": 9,
                "minimum": 0
            },
            "Left_ear_2000_Hz_hearing_threshold": {
                "unit_of_measurement": "",
                "maximum": 120,
                "tag": "Left ear 2000 Hz hearing threshold",
                "value": 7.5,
                "minimum": 0
            },
            "Left_ear_4000_Hz_hearing_threshold": {
                "unit_of_measurement": "",
                "maximum": 120,
                "tag": "Left ear 4000 Hz hearing threshold",
                "value": 5,
                "minimum": 0
            },
            "Left_ear_1000_Hz_hearing_threshold": {
                "unit_of_measurement": "",
                "maximum": 120,
                "tag": "Left ear 1000 Hz hearing threshold",
                "value": 9,
                "minimum": 0
            },
            "Left_ear_8000_Hz_hearing_threshold": {
                "unit_of_measurement": "",
                "maximum": 120,
                "tag": "Left ear 8000 Hz hearing threshold",
                "value": 8,
                "minimum": 0
            }
        }
    },
    "disabilities": {
        "Auditory": {},
        "Mobility": {},
        "Visual": {
            "Colour_blindness": {
                "icd_ref": "http://id.who.int/icd/entity/2028524981",
                "full_term": "Achromatopsia",
                "tag": "Colour blindness",
                "alt_terms": [
                    "Impairment of colour vision",
                    "Colour blindness"
                ],
                "desc": "",
                "Tritanomaly": {
                    "icd_ref": "http://id.who.int/icd/entity/733145819",
                    "full_term": "Tritanomaly",
                    "tag": "Tritanomaly",
                    "alt_terms": [],
                    "desc": "",
                    "Tritanomaly": {
                        "tag": "Tritanomaly",
                        "refLevel": "severity&placement",
                        "placement": [],
                        "severity": 0
                    },
                    "refLevel": "specification"
                },
                "refLevel": "disability"
            }
```

```
            }
        }
}
```

ANNEX B: John Doe's User Profile

The User Profile of John Doe is presented below in JSON format.


```
{
    "surname": "Doe",
    "name": "John",
    "tag": "Person",
    "version": "0.5",
    "id": "4:3c6f6109-bd93-4ffa-a0d0-fde76de0d71e:1445",
    "Cognitive_Information": {
        "tag": "Cognitive Information",
        "Modified_Mini_Mental_State_Exam_score": {
            "unit_of_measurement": "unitless",
            "maximum": 100,
            "tag": "Modified Mini Mental State Exam score",
            "value": "86.65",
            "minimum": 0
        },
        "Reaction_time": {
            "tag": "Reaction time",
            "Preparation_time": {
                "unit_of_measurement": "milliseconds",
                "maximum": 250,
                "tag": "Preparation time",
                "value": "246",
                "minimum": 25
            },
            "Initiation_time": {
                "unit_of_measurement": "milliseconds",
                "maximum": 500,
                "tag": "Initiation time",
                "value": "340",
                "minimum": 50
            }
        },
        "Reading_speed": {
            "unit_of_measurement": "words per minute",
            "maximum": 750,
            "tag": "Reading speed",
            "value": "485",
            "minimum": 20
        },
        "Digit_Symbol_Substitution_Test_score": {
            "unit_of_measurement": "correct answers in 90 seconds",
            "maximum": 110,
            "tag": "Digit Symbol Substitution Test score",
            "value": "56.61",
            "minimum": 0
        },
        "Writing_speed": {
            "unit_of_measurement": "letters per minute",
            "maximum": 260,
            "tag": "Writing speed",
            "value": "130.8"
            "minimum": 0
        }
    },
    "Visual_Information": {
        "tag": "Visual Information",
        "Color_vision": {
            "unit_of_measurement": "unitless",
            "options": [
                "Unimpaired",
```

```
                "Protanomaly",
                "Deuteranomaly",
                "Tritanomaly",
                "Protanopia",
                "Tritanopia"
            ],
            "tag": "Color vision",
            "value": "Unimpaired"
        },
        "Right_eye": {
            "tag": "Right eye",
            "Right_eye_peripheral_vision": {
                "tag": "Right eye peripheral vision",
                "Right_eye_superior_peripheral_vision": {
                    "unit_of_measurement": "degrees",
                    "maximum": 60,
                    "tag": "Right eye superior peripheral vision",
                    "value": 58.875,
                    "minimum": 0
                },
                "Right_eye_temporal_peripheral_vision": {
                    "unit_of_measurement": "degrees",
                    "maximum": 100,
                    "tag": "Right eye temporal peripheral vision",
                    "value": 96.625,
                    "minimum": 0
                },
                "Right_eye_nasal_peripheral_vision": {
                    "unit_of_measurement": "degrees",
                    "maximum": 60,
                    "tag": "Right eye nasal peripheral vision",
                    "value": 58.2,
                    "minimum": 0
                },
                "Right_eye_inferior_peripheral_vision": {
                    "unit_of_measurement": "degrees",
                    "maximum": 70,
                    "tag": "Right eye inferior peripheral vision",
                    "value": 67.975,
                    "minimum": 0
                }
            },
            "Right_eye_distance_vision_acuity": {
                "unit_of_measurement": "meters",
                "maximum": 300,
                "tag": "Right eye distance vision acuity",
                "minimum": 4,
                "value": 6
            },
            "Right_eye_contrast_sensitivity": {
                "unit_of_measurement": "logarithmic contrast value",
                "maximum": 2.25,
                "tag": "Right eye contrast sensitivity",
                "value": 1.7775,
                "minimum": 0
            },
            "Right_eye_near_vision_acuity": {
                "unit_of_measurement": "J",
                "maximum": 14,
                "tag": "Right eye near vision acuity",
                "minimum": 1,
                "value": 1
            }
        },
        "Left_eye": {
            "tag": "Left eye",
```

```
            "Left_eye_contrast_sensitivity": {
                "unit_of_measurement": "logarithmic contrast value",
                "maximum": 2.25,
                "tag": "Left eye contrast sensitivity",
                "value": 1.7975,
                "minimum": 0
            },
            "Left_eye_near_vision_acuity": {
                "unit_of_measurement": "J",
                "maximum": 14,
                "tag": "Left eye near vision acuity",
                "minimum": 1,
                "value": 1
            },
            "Left_eye_peripheral_vision": {
                "tag": "Left eye peripheral vision",
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                    "maximum": 0,
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                "tag": "Left elbow pronation",
                "value": 81.4,
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                "value": 86.4,
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                    "value": 136,
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                "value": 13,
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                "tag": "Left ear 2000 Hz hearing threshold",
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                "minimum": 0
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                "minimum": 0
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            "Left_ear_8000_Hz_hearing_threshold": {
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                "maximum": 120,
                "tag": "Left ear 8000 Hz hearing threshold",
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                "minimum": 0
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        "Mobility": {
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                "full_term": "Osteoarthritis",
                "tag": "Osteoarthritis",
                "alt_terms": []
                "Osteoarthritis_of_knee": {
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                    "full_term": "Osteoarthritis of knee",
                    "tag": "Osteoarthritis of knee",
                    "desc": "",
                    "alt_terms": [],
                    "Moderate_osteoarthritis": {
                        "tag": "Moderate osteoarthritis",
                        "refLevel": "severity&placement",
                        "placement": [],
                        "severity": 3
                    },
                    "refLevel": "specification"
                },
                "refLevel": "disability"
            }
        },
        "Visual": {}
    }
}
```

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This project has received funding from the European Union's Horizon Europe research and innovation programme under the grant agreement number 101147722. The European Union is not liable for any use that may be made of the information contained in this document, which is merely representing the authors' view.