

humantech

D4.2 – Intelligent exoskeleton with intention prediction prototype



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D4.2 - Intelligent exoskeleton with intention prediction prototype

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Acronyms and definitions

Acronym	Meaning
DoF	Degree of Freedom
HRC	Human Robot Collaboration
HW	Hardware
SW	Software
WRMD	Work-related musculoskeletal disorder
HT	Humantech
BSN	Body Sensor Network
IMU	Inertial Measurement Unit

Abstract

Work-related musculoskeletal disorders (WRMDs) are the most common occupational health problem in Europe. They have significant prevalence and impact in the construction sector.

In recent years, exoskeletons have been proposed as the solution to all the problems associated with WRMDs. However, the promise of effortless work thanks has not yet been fulfilled due to the inherent limitations of the technologies currently used in exoskeletons. One of these barriers is their usability and acceptability.

The aim of task 4.2 “Intention prediction and exoskeleton integration” is the design of an exoskeleton with automated activation based on the prediction of the intention of its wearer. Such an exoskeleton will minimize the cognitive and physical burden of interaction between it and its wearer. This deliverable presents the first prototype of this intelligent transparent exoskeleton.



The HumanTech project

The European construction industry faces three major challenges: increase the safety and wellbeing of its workforce, improve its productivity, and become greener, making efficient use of resources.

To address these challenges, HumanTech proposes to develop **human-centred cutting-edge technologies** such as wearables for workers' safety and support and robots that can harmoniously coexist with human workers while contributing to the ecological transition of the sector.

HumanTech aims to achieve major advances in cutting-edge technologies that will enable a safe, rewarding and digital work environment for a new generation of highly skilled construction workers and engineers.

These advances will include:

- **Robotic devices equipped with vision and intelligence** that allow them to navigate autonomously and safely in highly unstructured environments, collaborate with humans and dynamically update a semantic digital twin of the construction site in which they are.
- **Smart, unobtrusive workers protection and support equipment.** From exoskeletons activated by body sensors for posture and strain to wearable cameras and XR glasses that provide real-time workers' location and guidance for them to perform their tasks efficiently and accurately.
- An entirely new breed of **Dynamic Semantic Digital Twins (DSDTs) of construction sites** that simulate in detail the current state of a construction site at the geometric and semantic level, based on an extended Building Information Modelling (BIM) formulation that contains all relevant structural and semantic dimensions (BIMxD). BIMxDs will act as a common reference for all human workers, engineers, and autonomous machines.

The **HumanTech consortium** is formed by 22 organisations — leading research institutes and universities, innovative hi-tech SMEs, and large enterprises, construction groups and a construction SME representative — from 10 countries, bringing expertise in 11 different disciplines. The consortium is led by the German Research Center for Artificial Intelligence's Augmented Vision department.



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1. INTRODUCTION

Work-related musculoskeletal disorders (WRMDs) are the most common occupational health problem in Europe. Their origin is due to multiple causes. Except for processes solely caused by accidental injuries (overexertion), in almost all cases, several risk factors are involved in the onset of WRMDs, related to the task and the organization of work.

Despite enormous advances in robotics and automation in recent years, construction remains a labour-intensive task. While workers bring versatility and robustness to tasks that machines (robots) initially cannot achieve, humans remain intrinsically fragile when it comes to the physical demands of manual assembly. The construction sector faces the same challenges as other industries: a lack of skilled workers and an aging workforce. The above-mentioned risk factors particularly affect older workers, who are physiologically more vulnerable.

In recent years, exoskeletons have been proposed as the solution to all problems associated with WRMDs. It was thought that by transferring the loads of physically demanding work to these mechatronic devices, which follow and reinforce our every movement, we would become bionic superhumans, insensitive to the strains of manual work. However, the promise of effortless work thanks to exoskeletons has not yet been fulfilled in the real world. This is due to the inherent limitations of the technologies currently used in exoskeletons.

The objective of “WP4 - Wearable Technologies for Construction” is the integration of the Humantech wearables into one intelligent system that supports construction workers on demand and transparently without obstruction. Two of these wearables are the body sensor network (BSN) and the exoskeleton. The BSN, developed in “T4.1 - Inertial sensors - wearable camera integration “, provides information about the worker kinematics. This information is obtained from a network of IMUs distributed over his/her body. Kinematic information is used by the exoskeleton controller, developed in “T4.2 – Intention prediction and exoskeleton integration“, to infer the human intention and adapt the exoskeleton behaviour to it. Figure 1 shows the structure of WP4 and how it relates to other WPs.

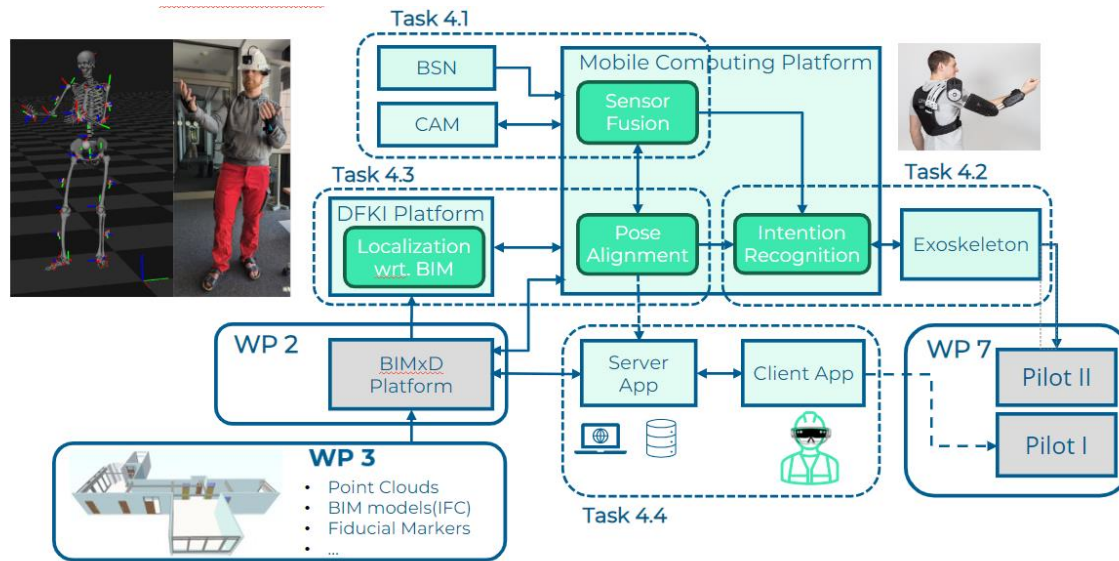


Figure 1 – Structure of WP4 and how it relates to other WPs. The current deliverable covers

This document describes the intelligent exoskeleton with intention prediction prototype designed and developed in Humantech. The document is organized as follows:

- Chapter 1 – Introduction: This chapter provides an overview of the problem statement, the organization and scope of “T4.2 - Intention prediction and exoskeleton integration”, and its relationships with other tasks within WP4. Additionally, it outlines the structure of this document, providing a roadmap for understanding the contents that follow.
- Chapter 2 – Exoskeletons in construction: This chapter describes the motivation behind the development of a novel exoskeleton for the construction industry. It provides an overview of work-related musculoskeletal disorders, highlighting their prevalence and impact in the construction sector. The chapter also explains why Humantech has decided to focus on upper-limb extremities and argues that existing solutions are not enough, necessitating the creation of more intelligent solutions.
- Chapter 3 – HumanTech exoskeleton use-case: This chapter presents the use-case which will serve as demonstrator for the exoskeleton prototype. It also describes the protocol based on the use-case, which will allow the systematic collection of necessary data to train the algorithm responsible for inferring the intentions of the exoskeleton wearer.
- Chapter 4 – HumanTech Exoskeleton prototype: This chapter delves into the developments undertaken within the Humantech project. It begins by



introducing the initial framework that will serve as the foundation for the prototype. Subsequently, it provides a detailed account of the hardware (HW) and software (SW) modifications implemented to achieve the task's objective: designing an exoskeleton capable of predicting the user's intention and adapting to it in a seamless and unobtrusive manner.

- Chapter 5 - Conclusions and future steps: This chapter will summarize the key findings and insights from the document. It will also present how the results of this document will be exploited.

2. EXOSKELETONS IN CONSTRUCTION

A work-related musculoskeletal disorder (WMSD) is an injury to the muscles, tendons, ligaments, nerves, joints, cartilage, bones, or blood vessels of the arms, legs, head, neck, or back that occurs or worsens for tasks that a job entails such as lifting, pushing or moving objects. The causes are diverse, but the most frequent origins for musculoskeletal disorders are: physical overexertion (38.0%), blows or collisions against a stationary object (working person in motion) (24.7%) and collisions or hits against a moving object (14.4%).

Workers in the construction industry are known to have increased rates of WMSDs with the back and shoulders being the most affected body regions [1]. While there are many different intervention approaches to control WMSDs in construction [2] [3] several construction tasks remain physically demanding, involve frequent exposure to known WMSD risk factors, and can be challenging to redesign or eliminate.

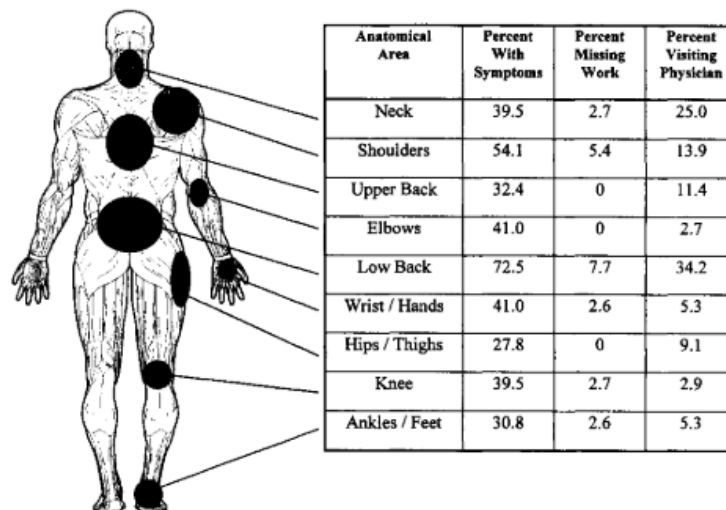


Figure 2 – Results of musculoskeletal symptom survey from bricklayers [1]

One potential tool to prevent WMSDs in construction is the use of exoskeletons. Exoskeletons can be defined as personal assistance systems that affect the body mechanically, helping its musculoskeletal system to perform a certain task or movement. Depending on the scope of application we have medical, military and occupational exoskeletons (OEs), which are those that aim to reduce the worker's muscular stress.

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We can classify occupational exoskeletons in different ways depending on the question asked:

- What is the origin of assistance energy? Active exoskeletons have electric, hydraulic, and pneumatic actuators while passive ones have springs and elastic elements that harvest energy in one movement and release it in another. Due to its lightness and smaller volume, its ease of maintenance and its cost, the passive exoskeleton is the one that has had the greatest introduction.
- What part of the body do they support? Manufacturers have specialized in small exoskeletons to support a specific area. There is a type for practically every area of the body: upper extremity, lower extremity, lumbar, hand, neck, and even thumb. Lumbar and shoulder are the most popular. However, the tendency is to combine them into modular exoskeletons and add/remove parts depending on the needs.
- How are they built? Rigid exoskeletons have a kinematic structure of non-deformable elements while flexible ones do not have this chain and are made up of elastic and/or deformable elements. The rigid ones can in turn be anthropomorphic or non-anthropomorphic depending on the degree of similarity and adaptation to the kinematics of the human body.

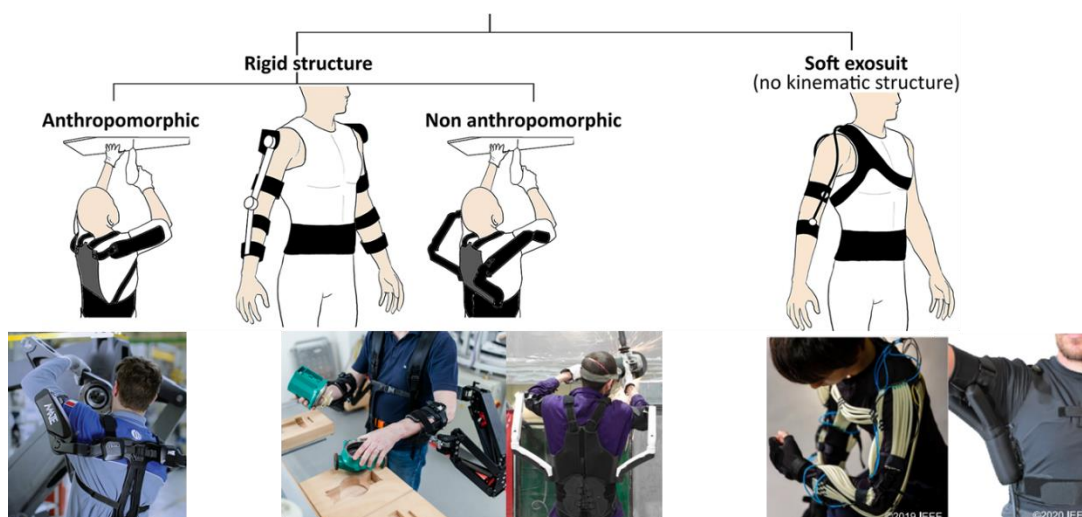


Figure 3 – Exoskeleton types according to how they are built [4]

In recent years, the potential application of OEs for the construction industry has gained interest in the research community. Proof of this are the studies that have been carried out to evaluate the performance of OEs based on increased worker safety, worker

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acceptance of the OE, and effects on worker productivity for concrete construction trades [5] [6]. The exoskeletons used in the studies are standard ones not specifically designed for construction tasks. However, there exist in the market some exoskeletons which have taken to account this target from their design.

HILTI together with Ottobock developed an upper-limb exoskeleton to support construction workers (EXO-O1). This exoskeleton is just a repackaging of an Ottobock already existing exoskeleton called Paexo Shoulder [7]. Swedish building and construction company, Peterson & Hansson, tested it for 3 months and their workers commented on the significant improvements that they have felt in their shoulders by the end of the day [8]. This exoskeleton has evolved to model Exo-S which incorporates support for neck.

There are other upper-limb exoskeletons targeting the same body area, however, Festool-ExoActive claims to be the first active exoskeleton for over shoulder construction tasks [9]. Its operation is based on the 18-volt lithium-ion battery which feeds the pneumatic actuators able to provide up to 50N of assistance to each of the arms. The activation and level of support is selected from a remote control. This exoskeleton was not available when Humantech project started.

An example of modular exoskeleton for construction is Fraco by Mawashi [10]. It consists of 3 modules each of them assisting one joint: knee, lower back and or shoulder. Fraco has up to 4 possible configurations to adapt the assistance depending on the users' needs. All the mechanisms are passive.

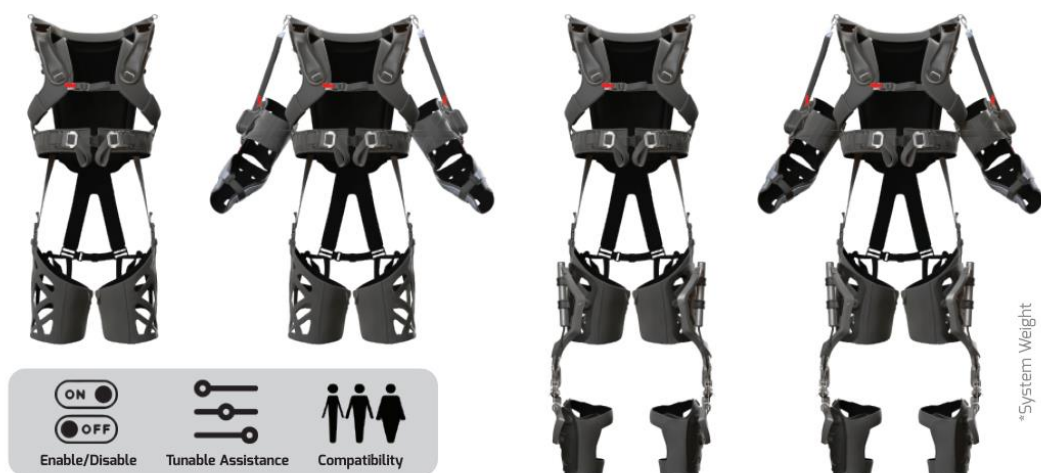


Figure 4 – Fraco exoskeleton configurations [10]



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Independently of being passive or active, the exoskeletons which have been introduced require interaction from the wearer for enabling the mechanisms and/or tune the assistance for the tasks. This is ok when the tasks are not very dynamic, and the user spend most of the time in a certain posture. However, when the movements are very different and dynamic, manually controlling the activation and regulation can be cumbersome.

3. HUMANTECH EXOSKELETON USE-CASE

The application scenario for the exoskeleton was collaboratively established with Humantech partner ACCIONA within the framework of WP7 – Pilots, Evaluation and Validation. The chosen activity for demonstration purposes was the construction of a brick wall focusing on those moments in which workers access a certain height. The goal was to have a use-case that would significantly impact construction workers, while also serving as an effective illustration of the concept of exoskeleton transparency through intention detection. The decision to focus on the upper limbs was driven by the recognition that the shoulder and elbow are two of the body regions most affected by the rigors of construction work. The construction of a brick wall was deliberately selected due to its repetitive nature, requiring frequent activations and deactivations of the exoskeleton. The overarching idea is to leverage the exoskeleton to alleviate the physical strain associated with the task, ultimately reducing the effort required by the worker while providing a more intuitive and less burdensome user experience, reducing the mental effort required to operate the exoskeleton.

3.1. Bricklaying

Bricklaying is seen as strenuous and a high-risk task for musculoskeletal disorders, particularly of the low back and shoulder. The participants in [1] described awkward postures of the back and shoulder when working, and handling bricks and mortar in these awkward postures, as the leading causes of their work-related musculoskeletal disorders. [11] coincides with the previous study and identifies other issues such as lack of space, poor work planning and variation in height.

Bricklayers spend 43% of their time building walls, 21% finishing the walls, resting for 17% and carrying out preparation work for 19% [12]. When building the walls, bricklayers usually work in pairs being one of them the responsible for the preparation and supply of the materials (assistant, in green in Figure 5) while the other (in red in Figure 5) raises the wall. The distribution of times for each of the tasks accomplished by these two workers in a working day is presented in Table 1.

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Table 1 - Mean time (in minutes) and standard deviation (SD) of tasks performed by Dutch traditional working bricklayers ($n = 10$) and bricklayers' assistants ($n = 10$) and as a percentage of total working time over a standardised observation period of 4.5 hours [13].

Tasks	Bricklayer			Bricklayers' assistant		
	Mean (min)	(SD)	%	Mean (min)	(SD)	%
Bricklaying	135.0	(13.2)	50	0.4	(1.0)	0.1
Preparation	49.6	(12.3)	18.4	40.0	(47.4)	14.8
Removing mortar	24.4	(9.3)	9.0	7.7	(17.2)	2.9
Consultation	2.6	(2.1)	1.0	11.6	(9.8)	4.3
Cleaning	2.5	(2.8)	0.9	7.7	(13.9)	2.9
Breaks	35.9	(4.9)	13.3	38.7	(7.3)	14.3
Intermediate task	1.1	(2.1)	0.4	1.8	(2.7)	0.6
Micro pauses	12.3	(11.5)	4.6	19.9	(12.3)	7.4
Transportation of materials	4.6	(4.1)	1.7	141.4	(60.1)	52.4
Other, undefined tasks	2.0	(1.5)	0.7	0.8	(1.1)	0.3
Total	270		100	270		100

Humantech has designed and developed solutions for helping both workers. The aim of “WP5 - Construction Robotics and Human-Robot Collaboration” is the deployment of Human-Robot collaboration (HRC) technologies for construction scenarios. Within this WP, a robotic platform (“T5.3 - On-site support robotic platform”) and a set of technologies (“T5.4 - Advanced perception for robots”, “T5.6 - Safe human-robot collaboration”) have been built that will help the “green” worker with the task of supplying material (bricks) to the other worker (Pilot 2 – Use Case 2- Collaborative Wall Building). The “red” worker, responsible for building the wall, will be assisted by an exoskeleton that will support those situations in which the bricklayer is working above shoulder height (Pilot 2 – Use Case 2 - Exoskeleton assisted over shoulder wall construction). The aim of “WP4 - Wearable Technologies for Construction” and more concretely “T4.2 - Intention prediction and exoskeleton integration”, is the development of such exoskeleton.

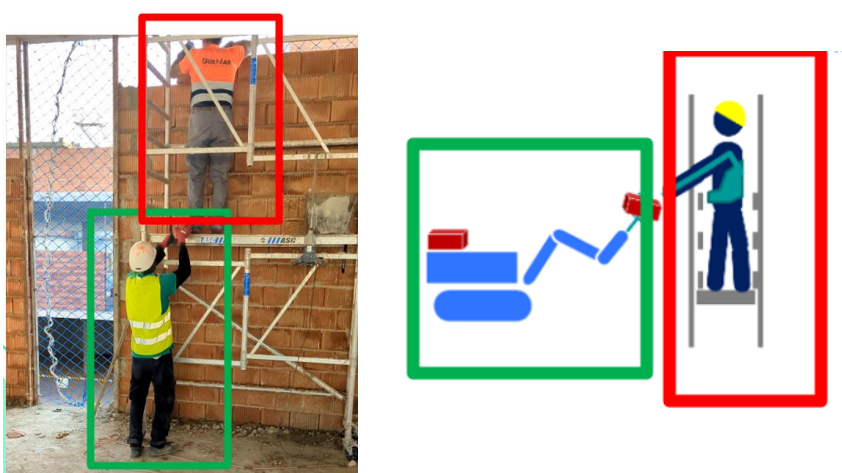


Figure 5 – Bricklayers working in pairs. The green worker (assistant) supplies material to the red worker which builds the wall. While the green worker will take more advantage of HRC technologies (WP5), the red worker will benefit from exoskeleton (WP4).

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Once the foundations have been laid, the process of building the wall consists of the following repetitive cycle (the information is a summary of Annex1 – Wall building technical note):

1. Place a mortar layer.
2. Place the first brick of the line and remove the excess of mortar.
3. Repeat
 - a. cover the end of the next brick with mortar.
 - b. place the brick and press against the previous brick and the base mortar.
 - c. use the level to check the alignment.

The materials and tools employed by the bricklayers are bricks, mortar, trowels, and leveller. These elements are normally on the floor (of the scaffold), so the worker must lift them from this height. Bricks for building walls weight around 2kg while a trowel loaded with mortar is around 2.3Kg [14]. Building a wall is a highly repetitive task, stressful for the body, that can get even worse when it is done with weight and above shoulder/below knee.



Figure 6 – A bricklayer at two different moments of its routine. Bricklaying is highly repetitive task which risk injury increases with weight and when working below knee (on the left) and above shoulder (on the right).

3.2. Protocol description

Upon the determination of the use-case, a meticulously crafted protocol was established to ensure the systematic and precise gathering of data essential for training the intention detection algorithm. This protocol intricately outlines the task that must be replicated, delineates the specific information to be captured, identifies the requisite equipment and materials, and defines the characteristics of the population sample to be involved in the data collection process.



3.2.1. Task steps

The task to be replicated consists of building two lines of wall starting at shoulder height. The first line will have 8 bricks while the second line will have 7 bricks. The starting height is worker dependant and must be regulated according to him/her. The process will follow the steps described below:

1. Simulate placing of mortar line. The participant will:
 - a. pick the trowel with weight from floor level with the right hand.
 - b. simulate picking mortar from a bowl at floor level and placing it over the line.

These steps will be done 4 times (this is the number of times considered to cover the line).

2. Leave the trowel with weight and pick the one without weight from floor level with the right hand.
3. Place the first brick of the line. The participant will:
 - a. pick the brick from floor level with left hand.
 - b. place it at the starting point.
 - c. simulate removing the excess of mortar with the trowel.
4. Place the rest of bricks of the line. The participant will:
 - a. pick the brick from floor level with left hand.
 - b. simulate putting some mortar at the end of the brick.
 - c. place it pressing against the previous brick and the mortar line.
 - d. simulate removing the excess of mortar with the trowel.

These steps will be repeated $N-1$ times being N the number of bricks of the line.

Steps from 1 to 4 will be repeated for the second line ($N=7$).

3.2.2. Data

While the intention detection algorithm will use kinematic information, the capture of muscular activity and centre of pressure data has been incorporated into the process. This information will be used for subsequent comparisons between conditions with and without the exoskeleton.

In terms of kinematic data, it was discerned that key parameters such as elbow flexion/extension, shoulder abduction/adduction, shoulder flexion/extension, and back

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angle were essential for a comprehensive understanding of the user's movements. The kinematic information will be captured at 100Hz.

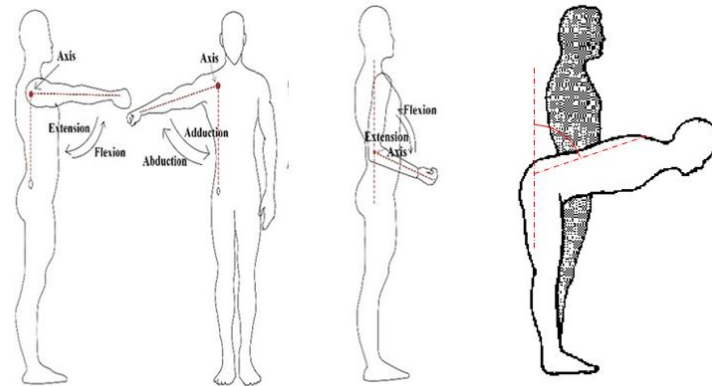


Figure 7 – Kinematic information of interest. From left to right: shoulder flexion/extension, shoulder abduction/adduction, elbow flexion/extension and back angle with regard the vertical.

Regarding muscular activity the following muscles will be monitored:

- Anterior deltoid (AD), Medium Trapezius (MT), Latissimus Dorsi (LT): these muscles are responsible of the shoulder flexion/extension and abduction/adduction.
- Biceps Brachi (BB) and Triceps Brachi (TB): these muscles are responsible of the elbow flexion/extension.

The signal from these muscles will be captured at 1000Hz. The sensor will be placed on the body following SENIAM guidelines [15].

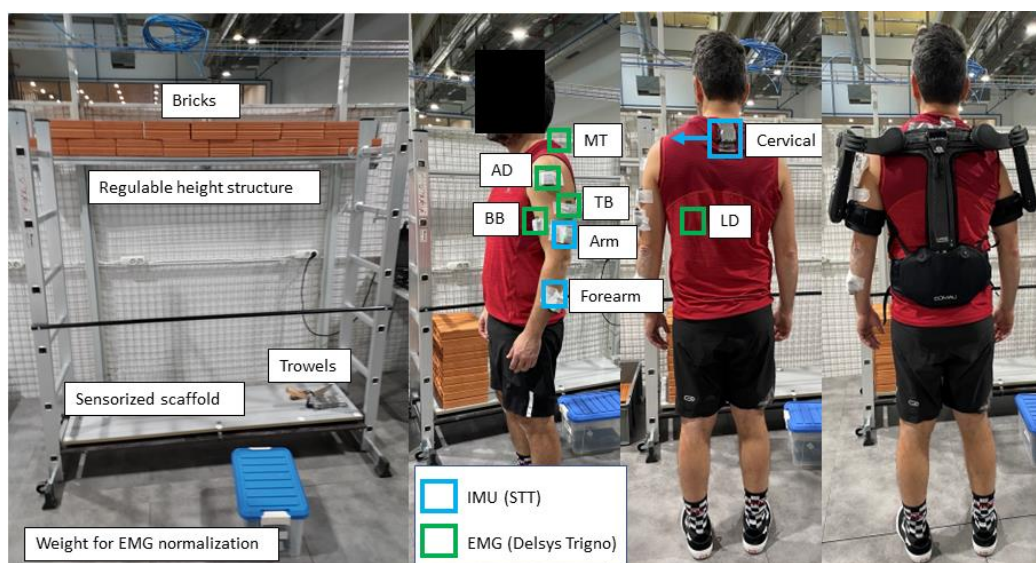


Figure 8 – Testbench (left) and location of the different sensors on worker's body (right).

3.2.3. Equipment/Testbench

Commercially available equipment for kinematic data (iSen STT) and for muscular activity (Delsys Trigno) is employed in the data capture process. Additionally, a customized solution was devised for the acquisition of center of pressure information. This involved the modification and sensorization of a standard scaffold, integrating four load cells for precise measurements. Beyond its primary function of providing centre of pressure data, the sensorized scaffold serves a dual purpose. Its design facilitates the reproduction of realistic working conditions, including scenarios with restricted workspace and potential interferences with surrounding structures.

The synchronization of the different data is achieved through the SW provided by iSen STT.

Table 2 – Summary of recorded data and equipments used for it

System	Type of sensor	Measure	Reference	More information
iSen STT	IMUs	Body Kinematics		Its SW provides the synchronization between the different data
Delsys	Surface EMG	Muscle activation pattern	EU_DS-T03-A08014	Trigno Avanti Sensors
Sensorized scaffold	Load cells	Center of Pressure		

Apart from the electronic equipment, a pair of trowels will be used. One of them has a load attached to simulate the weight of the mortar. A box with a total weight of 2Kg will be used for the normalization of the EMG.

4. HUMANTECH EXOSKELETON PROTOTYPE

4.1. Framework

Within the scope of the Humantech project, a development of an entirely new exoskeleton is not feasible. Consequently, following the identification of the use-case, efforts were directed towards procuring an upper-limb exoskeleton that would provide the foundational structure for the project's developments.

The selected exoskeleton was EduExo Pro from Auxivo [16]. EduExo Pro is an entire arm exoskeleton spanning the elbow and the shoulders with a total of 3 degrees of freedom. The lifting of the shoulder joint is supported by a mechanical spring, while the elbow joint movement is supported by a motor (5Nm). A load cell (10kg) in the lower arm and encoder in the elbow joint allow to know how much force the wearer is applying and the angle of elbow respectively. EduExo Pro has a microcontroller (Arduino nano [17]) which allow to program custom control algorithms for the exoskeleton. The exoskeleton attaches to the arms through cuffs and to the upper body through a vest.



Figure 9 – EduExo Pro from Auxivo. This exoskeleton is the base of Humantech's exoskeleton.

As previously commented, EduExo Pro exoskeleton is a good starting point to avoid starting a design from scratch, however it has some drawbacks that will be commented in next points together with the approach Humantech has taken to overcome them.

4.2. BSN

iSen IMUs (see 3.2.3 – Equipment/Testbench) were used in the first stages of the project to get information about the kinematics of a worker and train the intention detection algorithms. In the final version of the prototype the source of kinematic information is Humantech's BSN (see "D4.1 – Body sensor network with integrated camera approach").

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Humantech's BSN consists of an inertial sensor network developed by DFKI in the BIONIC project [18] which has been combined with a 360° camera developed by Ricoh within WP4. The integration efforts done by Sci-Track within "T4.1 -Inertial sensors - wearable camera integration" have been oriented to reduce the drift in the pose estimation of the inertial sensors system by combining its information with visual tracking. The information from both HW is collected and processed by Sensor Fusion component that runs in the on-body computing platform (Qualcomm Robotics Platform RB5 [19]) of the Humantech BSN.

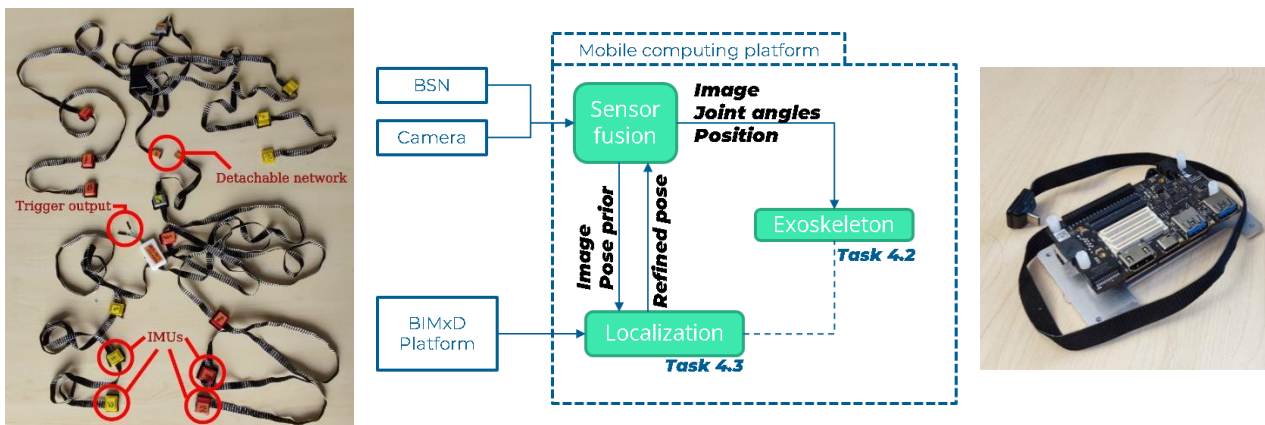


Figure 10 – From left to right: inertial sensor network, dataflow within WP4 and on-body computing platform.

The SensorFusion component is the responsible of sharing the joint angles information with other components such as the exoskeleton controller. Point "4.2.1-BSN-Exoskeleton interface" describes the interface used for sharing joint angles information between both components.

4.2.1. BSN-Exoskeleton interface

Point "3.2.2 – Protocol Data" define the kinematic information which was important for discerning user intention: elbow flexion/extension, shoulder abduction/adduction, shoulder flexion/extension, and back angle. This information is used by 2 components, the BSN which generates it and the exoskeleton controller which consumes it. Both components must share a common interface, so they have a common understanding of what information is shared (protocol) and how it is done (communication channel).

Regarding the protocol, the messages interchanged between the components respect the format specified in Table3. The fields in the message must be packed into byte arrays using the first character for indicating the byte order (little endian).

Table 3 – Message protocol of the BSN-exoskeleton interface

Name	Description	Unit	Type	Bytes
timestamp	Time since epoch.	ms	Long	8
shoulder_flex_r, shoulder_flex_l	Right/left shoulder flexion angle. 0° when hand pointing floor, positive when the arm is elevated.	degrees	Double	8
shoulder_abd_r, shoulder_abd_l	Right/left shoulder abduction angle. 0° when the hand is close to the body, positive when it is elevated.	degrees	Double	8
elbow_flexion_r, elbow_flexion_l	Right/left elbow flexion angle. 0° when the elbow is extended, positive when the elbow is flexed, negative when it is overstretched.	degrees	Double	8
back	Back angle with regard the vertical.	degrees	Double	8

With respect the channel of communication, to optimize efficiency and mitigate additional weight on the worker, both components were configured to run on the same computer. Despite the availability of more streamlined solutions for inter-process communication within a single machine, a TCP channel was chosen. This decision was motivated by the flexibility it affords in accommodating diverse architectures ensuring adaptability to varying system configurations. It also lets the developers use the IDE they are used to as there are implementations for all the programming languages.

4.3. HW modifications

As commented in point “4.1 - Framework”, the starting point for Humantech exoskeleton is a commercial one called EduExo Pro. Several mechanical and hardware limitations have been observed in the original design of the exoskeleton. This point describes these constraints and how Humantech prototype has tackled them.

4.3.1. Active shoulder

The mechanism for supporting the shoulder elevation in the EduExo Pro exoskeleton is a spiral torsion spring. The loads are applied to the inner (fixed) and outer (mobile) ends of the spiral providing a linear torque (M) that is proportional the angular change between both extremities (φ). The proportional constant depends on material characteristics (module of elasticity - E , density - ρ) and construction parameters (outer radius - R_o , inner radius - R_i , thickness - t , width - b , inter-coil distance - a).

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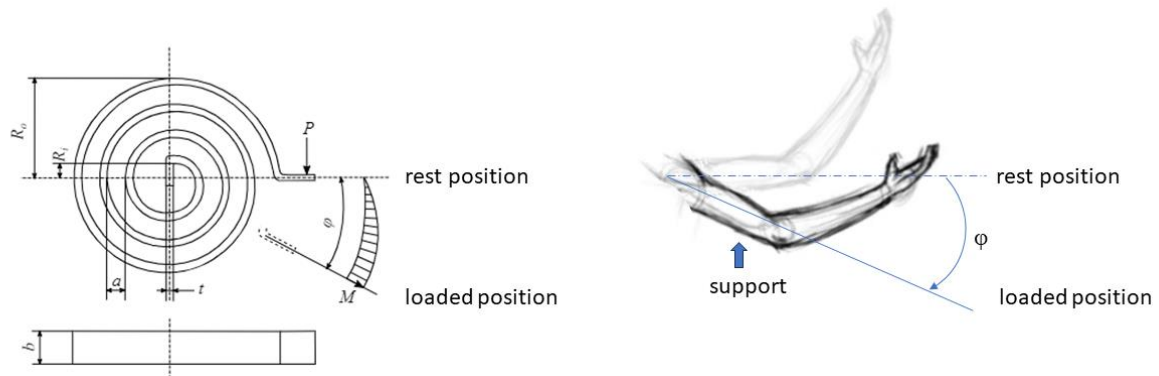


Figure 11 – Right: Torsion spiral spring, the provided torque is proportional to the deflection [20]. Left: The provided torque lead the arm to the rest position.

Whenever the spring is out of the rest position, a torque is generated that pushes the arm to the rest position. This behaviour is always active as EduExo Pro does not have clutches to engage /disengage it as other exoskeletons have. This means that the wearer has always to exert force to lower his/her arm to adopt relaxed posture with the arms close to the body or pick something from lower levels.

To improve the flexibility and be able to adapt the shoulder support to different situations, this passive DoF has been substituted by an active mechanism. The main component of this mechanism is a T8-16 actuator from Hebi Robotics [21].

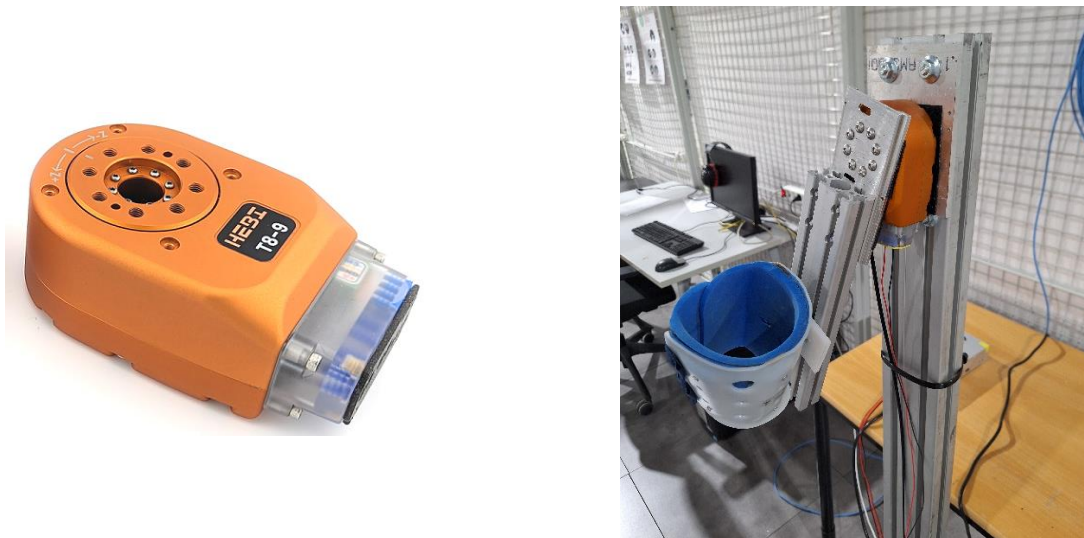


Figure 12 – Left: T8-9 from HEBI Robotics. Main difference between T8-9 and T8-16 is that the latest could provide bigger torques.. Right: T8-16 integrated in a testbench for testing purposes.

This element is a series-elastic actuator that integrates a brushless motor, geartrain, spring, encoders, and control electronics into a compact package. The output rotates continuously and does not require calibration nor homing. This actuator provides also

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cross-platform software tools so it can be configured and controlled from multiple platforms. The main features of this actuator are listed in Table 4.

Table 4 – T8-16 features [21]

Feature	Value
Peak torque	38Nm
Continuous torque	16Nm
Max speed	15rpm
Mass	575g
Dimensions	126mmx74mmx48mm
Power	24-48V Continuous current: 1.3A @ 36V Peak current: 3.0A @ 36V
Communication	2x100Mbps Plastic Optical Fiber
Angular resolution	0.005°
Torque resolution	0.01Nm
Backlash	+/-0.25°
Sensing	Angular position, angular velocity, output torque, 3-axis accelerometer/gyro, temperature, voltage, current
API support	Matlab (Windows/Linux/OS X), Python (Windows/Linux/OS X), C++ (Windows/Linux/OS X), ROS (Linux)

This component was chosen because it is a good option when having to do a fast prototyping: it has everything embedded in the same package, it can be controlled in multiple ways (position, velocity, torque) and it has libraries to be used from different platforms. It is also more adequate for the application because it provides bigger support to the shoulder that what it achieved with the torsional spring, and it can be enabled/disabled/regulated when needed. The main but minor drawback is also related with the all-in-one packaging. As everything is in the same package, no component can be moved to relieve some weight from the shoulder.

A bracket was designed to adapt the mechanical interface of the actuator to the mechanical interface of the exoskeleton.

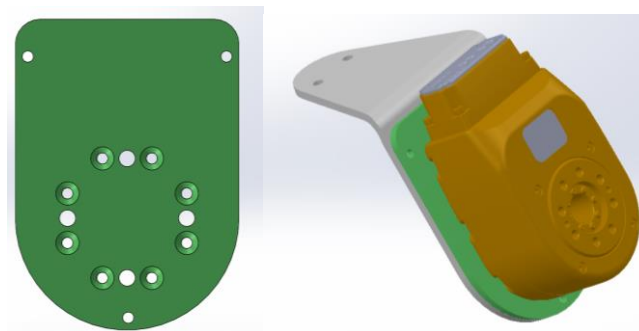


Figure 13 – Connection bracket between shoulder plate and HEBI actuator. Left: detail of bracket. Right: bracket location in between components.

4.3.2. Extra shoulder DoF

The shoulder joint is a complex joint that can be biomechanically modelled in its simpler version by and spherical joint [22].

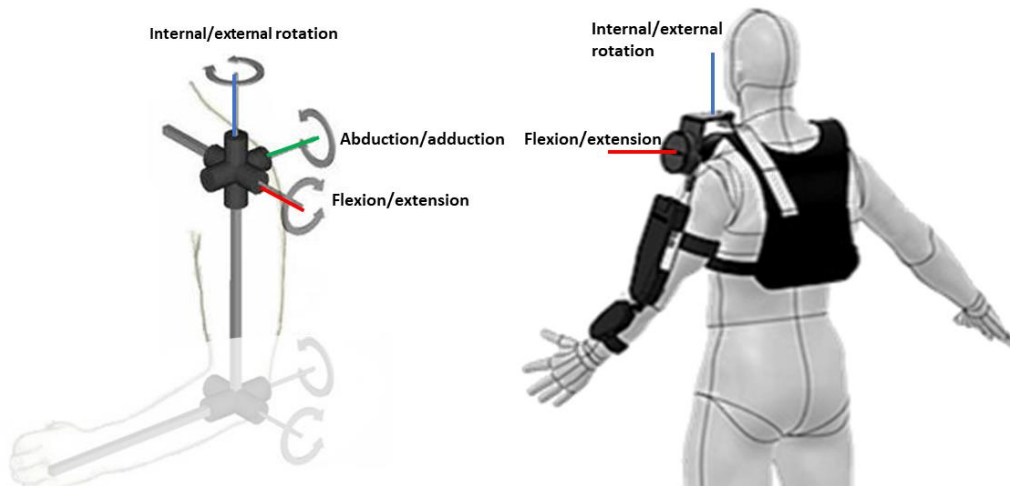


Figure 14 – Left: kinematic model of shoulder joint (3 DoF, adapted from [22]). Right: DoFs for shoulder in EduExo Pro (2 DoF).

Current version of the exoskeleton has only 2 DoF for the shoulder motion (flexion/extension and, internal/external rotation) so it limits some of the movements that the wearer does. An extra passive DoF affecting abduction/adduction has been added to better adapt to human kinematics.

4.3.3. Passive elbow

EduExo Pro has an electrically actuated elbow joint. The motor and a controller (arduino) provide the capability to program algorithms that provides certain intelligence/flexibility to the exoskeleton actuation.

The first idea was to use this motorized joint and implement an algorithm to avoid elbow hyper-extension. The objective was to keep the joint transparent until a defined limit for the elbow angle was reached beyond which no further movement in the extension direction was allowed.

An admittance controller was implemented but its performance was not good. To have the same behaviour and be able to limit the extension movement above certain angle, a simpler approach has been taken and the motorised joint has been substituted with a passive elbow joint with an extension ratcheting mechanism. The angle limit for the extension can be changed and enabled/disabled through a switch.

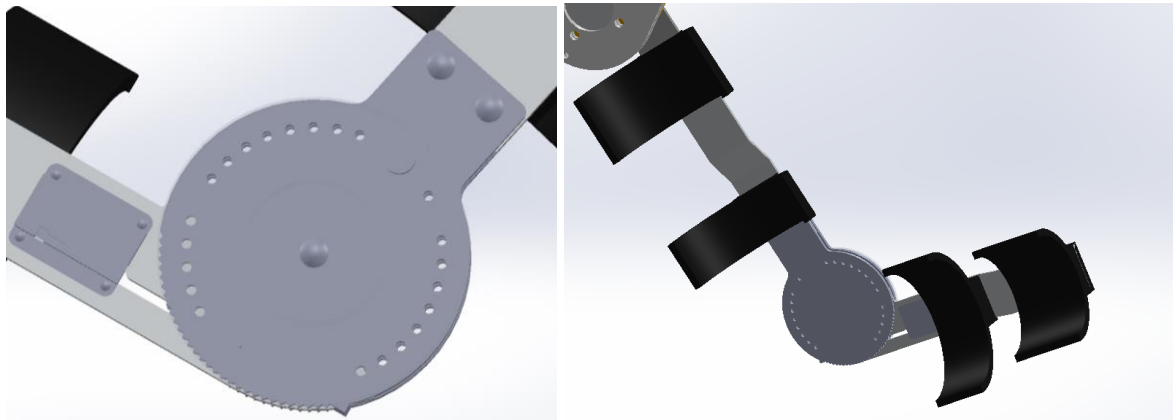


Figure 15 – Left: Detail of the passive elbow joint with extension ratcheting mechanism. Right: Elbow joint together with arm and forearm links

The links connecting to the elbow joint have been also replaced by others with an extra linear DOF which allows their easy adaptation to different morphologies of users. These links will be attached to the arm and forearm through cuffs with straps.

4.4. Exoskeleton controller

The exoskeleton controller has been divided in two levels. The high-level controller is the one responsible of predicting the intention of the wearer of the exoskeleton from the angles provided by the BSN. The inferred intention is then translated to an assistive torque by the low-level controller.

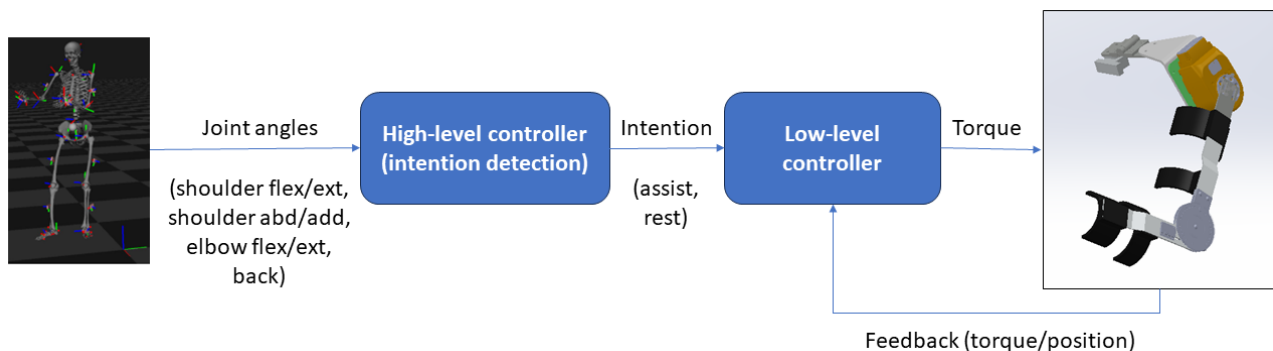


Figure 16 – Exoskeleton controller schema

4.4.1. High-level controller

The aim of the high-level controller is to infer the intention of the user from the body angles provided by the IMUs of the BSN. To achieve this, a machine learning model is trained using data collected from multiple users performing tasks of interest. Once trained, the model can evaluate new input samples and reliably determine the user's intention from them.

This section commences with a comprehensive review of state-of-the-art algorithms that utilize Inertial Measurement Units (IMUs) for intention prediction. This is followed by a presentation of the dataset employed for training these algorithms, as well as a detailed description of the methodology undertaken to arrive the solution implemented in HumanTech.

Intention detection based on IMUs

The use of machine-learning (ML) models to detect injury-prone postures is a dynamic area of research, particularly in the context of IMU-based posture analysis for construction workers [23]. Models such as Neural Networks (NN) [24], Support Vector Machines (SVM) ([25], [26]) and Long-Short Term Memory (LSTM) ([23], [27]) neural networks have been employed for this purpose using information of inertial sensors distributed along the body.

Of all the techniques mentioned above, LSTM (Long Short-Term Memory) neural networks are highly effective for detecting human intentions using IMUs due to the following advantages:

- Handling sequential data: IMU data typically involves sequential patterns of human movements, such as posture transitions. LSTM networks are specifically designed to manage sequential data and capture long-term dependencies in these patterns [28], which is crucial for accurate intention detection.
- Memory mechanism: LSTMs include a memory cell that can retain information for extended periods, enabling them to remember the context of movement sequences. This capability is beneficial for identifying subtle changes in posture or movement intentions [28].
- Flexibility in sampling rates: LSTMs perform well across various sampling rates, making them adaptable for multiple applications. For instance, a study demonstrated that the LSTM model achieved high accuracy (95%) even at a high sampling rate of 100 Hz [29], the data rate used in the HumanTech.
- Personalization and generalization: LSTMs can be trained on data from one individual and still perform effectively on data from others, demonstrating their potential for both personalized and generalized deep learning models [29]. One of the goals of HumantTech exoskeleton is to improve the usability and accessibility of this technology. Eliminating the need of a personalization procedure is aligned with this objective.

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- Real-Time Prediction: LSTMs are well-suited for real-time prediction tasks, which is essential for applications like human-robot interaction, where fast and precise intention detection is critical for smooth coordination [30].

In summary, the ability of LSTMs to manage sequential data, maintain context, adapt to varying sampling rates, and perform well across multiple subjects makes them an excellent choice for human intention detection using IMUs.

Dataset

As already explained in “3.2 - Protocol”, the dataset is essential for training the intention detection algorithm. The testbench described there has been used for capturing data of 4 users performing the task. The task was repeated 3 times for each of the users. The dataset was divided in two sets, one for training (containing data from all users) and the other one to check the quality of the trained model with regard a user.

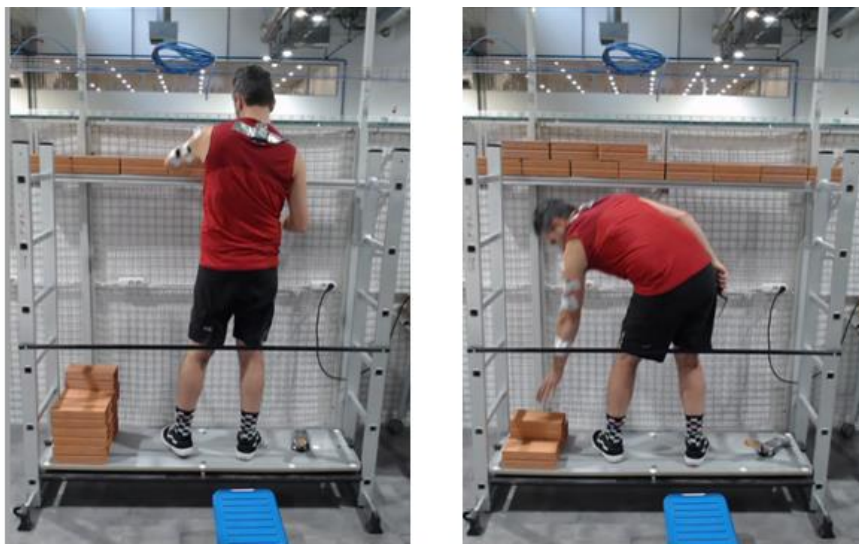


Figure 17 –One of the users in two moments of the recording.

Figure 18 shows an example of the recorded signals from the users.

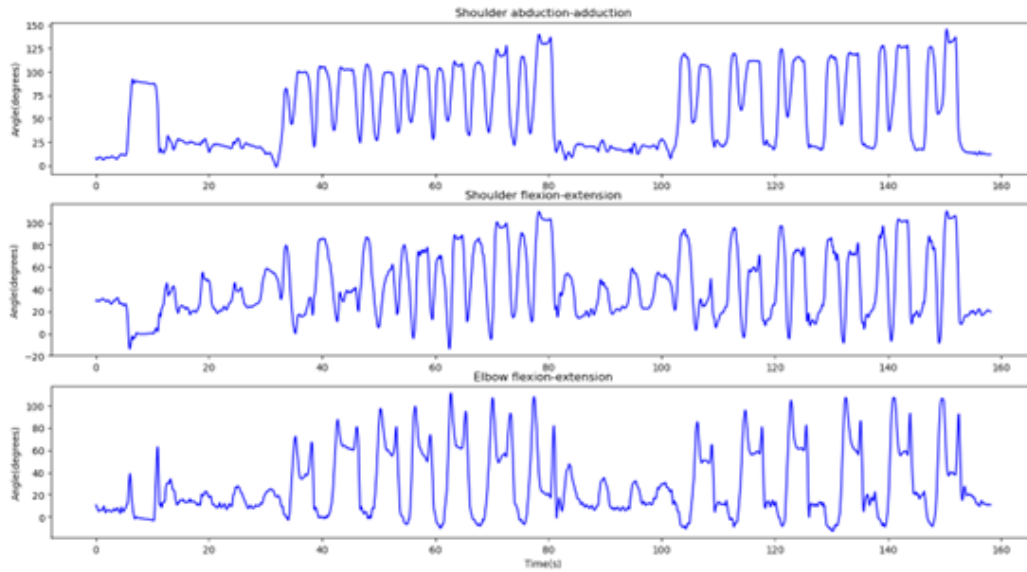


Figure 18 –Recorded signals. From top to bottom: shoulder abduction/adduction, shoulder flexion/extension and elbow flexion/extension.

Algorithm

The intention detection algorithm has been designed to take body joint angles as inputs and classify them into two categories: whether the exoskeleton should be activated or not.

Initially, a threshold-based approach was explored, aiming to bypass the need for manual frame labelling, which can be a laborious task. However, this method proved unsuccessful, regardless of the threshold values used. The algorithm generated double activations for each brick, whereas only a single activation was required.

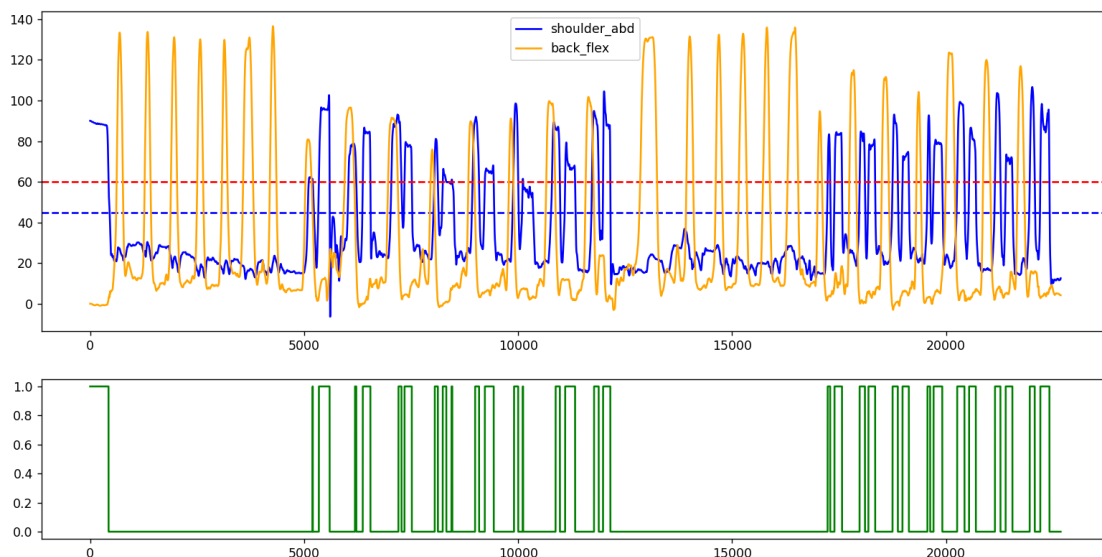


Figure 19 – Top: shoulder abduction/adduction (blue) and back angles (orange) in degrees. Bottom: exoskeleton activation (enable = 1.0, disable: 0.0). A double activation is generated for each of the bricks while only one is needed.



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Next, a Long Short-Term Memory (LSTM) neural network was employed to predict future angles based on current values and classify them using labelled frames. To optimize the network's performance, the following hyperparameters were automatically fine-tuned using "GridSearchCV" from scikit-learn [31]:

- Batch size, the number of samples to work through before updating the internal model parameters. A larger batch size can speed up training but may lead to less accurate models. A smaller batch size can lead to more accurate models but may slow down training.
- Epoch, number of complete passes through the training dataset. Increasing the number of epochs can lead to better model performance but may also lead to overfitting. Decreasing the number of epochs can prevent overfitting but may not allow the model to learn enough from the data.
- Optimizer, is an algorithm used to update the model's parameters to minimize the loss function. Different optimizers (SGD, Adam, RMSProp,...) have different learning rates, momentum, and adaptive learning strategies, which can affect the convergence speed and accuracy of the model.
- Weight initialization, is used to define the initial values for the parameters in neural network models prior to training the models on a dataset. Proper weight initialization can help the model converge faster and more accurately.
- Activation function, is a mathematical function that introduces non-linearity into the model, allowing it to learn more complex relationships between inputs and outputs. The choice of activation function can significantly impact the model's performance, convergence speed, and ability to generalize.
- Neurons, the number of neurons affects the learning capacity of the network. Generally, more neurons would be able to learn more structure from the problem at the cost of longer training time, but this may also lead to the problem of potentially overfitting the training data.

In our case the optimal combination that enhances predictive accuracy was:

- Batch size = 32
- Epoch = 50
- Optimizer = Adam
- Weight initialization = uniform
- Activation function= relu



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- Neurons 64 | 32

The LSTM neural network successfully eliminated the double activation issue, but unfortunately, its overall performance was still subpar. Despite optimizing the model's parameters, it only managed to achieve an accuracy of 63%.

Given the limited success of predicting angles, a new approach was explored, where the algorithm directly predicted the class instead of the angles. Through rigorous optimization, the LSTM's parameters were fine-tuned to yield the following values:

- Future = 25. This means that the algorithm can predict the future with 25 frames in advance. If reception rate is 100Hz, that means that the algorithm can infer the future with 250ms of advance.
- Window length = 75
- Overlap = 0.25
- Batch size = 10
- Epoch = 10
- Optimizer = Adam
- Weight initialization = uniform
- Activation function= sigmoid
- Neurons 50 | 50

To investigate the importance of different inputs on the algorithm's performance, the model was tested with various combinations of input types and number. Specifically, the impact of different angles and their velocities of change was examined. The outcomes of this analysis are presented in Table 5, which summarizes the accuracy of the algorithm under different input configurations.

Table 5 – Algorithm inputs vs. accuracy (shoulder flexion/extension-SFE, shoulder abduction/adduction-SAA, elbow flexion/extension-EFE, back-B)

Inputs	Accuracy (%)
4 inputs: 4 angles (SFE, SAA, EFE, B)	87.62%
6 inputs: 3 angles (SFE, SAA, B), 3 velocities (SFE, SAA, B)	79.61%
7 inputs: 4 angles (SFE, SAA, EFE, B), 3 velocities (SFE, SAA, EFE)	86.95%
8 inputs: 4 angles (SFE, SAA, EFE, B), 4 velocities (SFE, SAA, EFE, B)	88.76%

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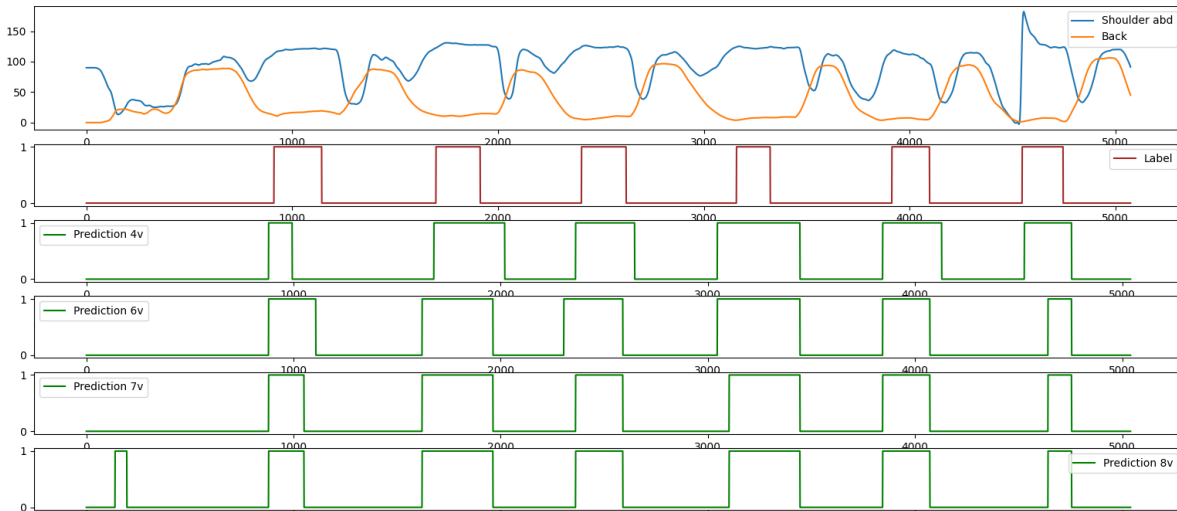


Figure 20 – First plot: shoulder abduction/adduction (blue) and back angles (orange) in degrees. Second plot: Reference class (enable = 1.0, disable: 0.0). Third plot: Predicted class (4 angles). Fourth plot: Predicted class (3 angles, 3 velocities). Fifth plot: Predicted class (4 angles, 3 velocities). Sixth plot: Predicted class (4 angles, 4 velocities)

An accuracy below 100% indicates that the exoskeleton may activate or deactivate either prematurely or belatedly. Among these scenarios, delayed deactivation is particularly concerning, as it forces the user to contend with additional torque, potentially making movement more difficult. To keep the pipeline as simple as possible and as the variation of accuracy was not high, the decision of using only the 4 angles was taken.

The algorithm was implemented using Python [32] and Tensorflow [33] library. Its performance was tested in both a PC and the on-body platform. The on-body platform required a specific building procedure because the dependency of Tensorflow library on HDF5 [34], which needed to be compiled specifically for the platform's architecture. The processing time for each prediction was 2ms on the PC ([i7@2.6Ghz](#) x 12, 16GB RAM) and 25ms on the on-body platform (RB5), both of which are below the 250ms with which the algorithm can infer the future. However, the processing time of the low-level controller and the response time of the actuator should be also considered to say that the exoskeleton is able to predict the future.

4.4.2. Low-level controller

The low-level controller is the responsible to interact with the exoskeleton hardware and will transform the predicted classes into adequate commands.

As commented in point “3 – Humantech exoskeleton use-case”, the shoulder and the elbow were two areas with more WRMD incidences between bricklayers. Within task “T4.2 - Intention prediction and exoskeleton integration”, two controllers (elbow hyper-

extension avoidance and shoulder assistance) have been developed to help with the problem.

Elbow hyper-extension avoidance

Before discarding the active elbow of EduExo Pro, some experiments were done to check how a controller for avoiding elbow hyper-extension could work.

As the EduExo Pro exoskeleton provides a sensor to measure the force that the wearer is applying against its frame and the servo is controlled in position, an admittance controller approach was taken. The idea was to keep the joint transparent until a defined limit for the elbow angle was reached beyond which no further movement in the extension direction was allowed.

This controller was implemented in Arduino. The position sensor in the servo was used to know the elbow angle (instead of the one provided by the IMUs). The signal coming from the load-cell was noisy, so it was low-pass filtered. The obtained joint behaviour was not as compliant as desired because the characteristics of the servo. Consequently, a decision was made to replace the elbow joint with a passive one.

Shoulder assistance

As commented in point "4.3.1-Active shoulder", the original spring mechanism was substituted by a motorized one. This provides more flexibility to the joint in terms of adaptability to different situations.

The shoulder's low-level controller takes inputs from the user's intention, provided by the high-level controller, and the actuator's status to generate torque as the output. When the exoskeleton is in the "disable" state, the torque is adjusted to ensure the joint remains transparent. In the "enable" state, the torque is increased to provide additional assistance, helping to keep the arm lifted.

The initial configuration of the actuator and the communication between the controller and the actuator is done through an Ethernet cable using the python package that HEBI provides.

4.4.3. Performance tests

The full controller (high-level and low-level controller) has been tested together with shoulder actuator using the testbench in Figure-12 for both a PC ([i7@2.6GHz](#) x 12, 16GB RAM) and the on-body platform (RB5). The measured time for all the process (angle reception, intention detection, torque generation and reach the desired objective) was



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about 175ms for the PC and 205ms for the RB5. Both values are below the future window (250ms) so it can be concluded that the exoskeleton controller is able to anticipate the intention of the user and adapt accordingly.



5. CONCLUSIONS AND FUTURE STEPS

This deliverable describes the work accomplished within “T4.2 - Intention prediction and exoskeleton integration” that has generated as result the first version of HumanTech exoskeleton prototype. Designed for the upper limb, this exoskeleton aims to reduce the strain on bricklayers' arms and shoulders when working at elevated heights. Its primary feature is its ability to predict the user's intention and adapt its assistance accordingly, while remaining unobtrusive to the wearer.

The next step involves evaluating the exoskeleton in a controlled working environment. This effort will be a collaboration among "WP4 - Wearable Technologies for Construction," "WP6 - Human Factors - Training and Usability Assessment," and "WP7 - Pilots, Evaluation and Validation." WP6 will be responsible for defining the testing protocol, including the evaluation metrics and the specific tasks and equipment to be used. The actual evaluation will take place within WP7, specifically under "Pilot 2 - Use Case 2: Exoskeleton-Assisted Over-Shoulder Wall Construction." The conclusions and results from this evaluation will be analysed by WP4 to enhance future versions of the prototype. This cyclical refinement process is a key component of the defined exploitation roadmap towards a final product that aligns with market and user demands.

6. ANNEXES

6.1. Wall building technical note

A. CONSTRUCCIÓN DE UN MURO DE LADRILLOS

A.1. MATERIALES Y HERRAMIENTAS

Existe una gran variedad de ladrillos: cocido de tierra, macizo, de adobe de tierra, refractario, hueco, etc. Todos los tipos de ladrillos pertenecen a tres categorías principales.

- Resistentes a la intemperie: pueden soportar el contacto directo con la tierra y la humedad. Ideales para la construcción de cimientos, patios, paredes de jardines, etc.
- Resistencia intermedia a la intemperie: pueden soportar temperaturas de congelación y trabajo por encima del suelo (pero no en contacto directo con él).
- No resistentes a la intemperie: se usan para trabajos en interiores.

Se tendrá que calcular los ladrillos que se van a necesitar según el muro que se quiera levantar. La medida estándar de un ladrillo es de 9.2 x 5.7 x 19.3 cm. Se debe sumar el espacio entre ladrillos que irá relleno de mortero, el cual debería estar entre los 1.5 – 2 cm.

Aparte de los ladrillos, para levantar un muro, se necesita el mortero para unirlos. Se pueden comprar sacos con el mortero en polvo ya preparado para mezclar con el agua, en lugar de tener que hacer la mezcla con arena y cemento.

Aunque se compre el mortero en sacos, se necesita hacer hormigón o usar cemento (es más fácil esta opción) para hacer los cimientos del muro de ladrillos.

En cuanto a herramientas, lo básico que se va a necesitar es lo siguiente:

- Cuerda y abrazaderas o clavos (para crear las cuerdas guías)
- Capazo o balde para mezclar el mortero
- Mezclador eléctrico si se quiere realizar una mezcla perfecta y sin esfuerzo
- Paleta
- Llana
- Llaguero
- Martillo
- Cinta métrica
- Lonas, plásticos o madera contrachapada para colocar en la base de la pared y evitar manchar todo el suelo de mortero.
- Nivel de torpedo pequeño para revisar los ladrillos individualmente
- Nivel de 120 cm aprox.
- Pala

A.2. PROCESO CONSTRUCTIVO

PASO 1: EXCAVAR UNA ZANJA PARA EL CIMIENTO

Se tiene que excavar una zanja dónde se colocará la base de la pared, la cual se solidificará después con una capa de hormigón o cemento.

Se hace una zanja rectangular que sea de la longitud y el ancho de la pared que se quiera hacer y que tenga aproximadamente 30 o 40 cm de profundidad. Según la altura que se quiera dar al muro, probablemente se necesite una zanja más profunda o ancha.

Es importante asegurarse de que la base tenga un buen drenaje de agua lejos de la pared, para evitar su acumulación alrededor.

PASO 2: CLAVAR ESTACAS DE MADERA EN LA ZANJA

Se clavan las estacas de modo que todas las puntas superiores estén al mismo nivel. Hay que tener en cuenta la altura nominal de los ladrillos (la altura de los ladrillos más el mortero), y luego clavarlas de manera que todas estén a esa altura, por debajo de la parte superior de la zanja.

Así, la primera fila de ladrillos quedará completamente dentro del cimiento. Utilizar un nivel para asegurar de que las puntas superiores de las estacas estén completamente niveladas, y dejar un espacio de 60 – 120 cm entre las estacas dependiendo de la longitud de la pared.

PASO 3: LLENAR LA ZANJA DE HORMIGÓN O CEMENTO PARA UN MURO DE LADRILLOS

Llenar hasta la parte superior de las estacas, dejando el espacio hasta el borde de la zanja que se midió para la primera fila de ladrillos.

Asegurarse de que la parte superior del cemento esté lisa y nivelada antes de que comience a secar. El hormigón o el cemento tardan entre 2 y 3 días en fraguar.

PASO 4: CONSTRUIR LOS POSTES INDICADORES O BARRAS DE MEDICIÓN

Estos postes indicadores o barras de medición ayudarán a asegurar que la pared esté nivelada. Para eso hay que tomar 2 tablas y marcar con clavos en el lugar dónde debe ir cada fila de ladrillos, también conocidas como hiladas, contando con el grosor del mortero.

Asegurarse de poder clavar las tablas en el suelo en ambos extremos del muro para que se aguanten sin necesidad de apoyo. Estas deben ser de la misma altura que la pared que se construirá.

PASO 5: COLOCAR LONAS O MADERA

En la base del muro, hay que colocar las lonas o madera para atrapar el exceso de mortero mientras cae.



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PASO 6: COLOCAR LA PRIMERA FILA DE LADRILLOS DEL MURO DE LADRILLOS

Colocar la primera fila en el cimiento para ensayar la ubicación, tomando en cuenta el mortero. Utilizar la cinta métrica para asegurarse de que estén a una distancia correcta y de que encajen cómodamente en la zanja.

Planificar cómo será toda la primera fila antes de comenzar a construirla.

PASO 7: LÍNEA RECTA NIVELADA

Unir la primera marca de clavos de ambas tablas con un hilo o cuerda que hará de guía, permitiendo mantener una línea recta nivelada con la que trabajar.

PASO 8: NUEVA FILA EN EL MURO DE LADRILLOS

Se irá subiendo de clavo a medida que se construya una nueva fila. Esto servirá a partir de la segunda fila de ladrillos, ya que la primera quedará enterrada en la zanja.

No dejar que el hilo o cuerda se afloje. Es necesario que se mantenga tenso para construir una pared nivelada, sólida y sin problemas estructurales.

PASO 9: REMOJAR LOS LADRILLOS EN AGUA

Remojar los ladrillos en agua y esperar hasta que ya no corra el mortero podría quedar demasiado aguado. Pero si no se mojan, absorberán el agua del mortero provocando problemas en su fraguado.

Esto se conoce como "afogarado" del mortero y se debe evitar a toda costa, mojando bien los ladrillos.

PASO 10: PRIMERA CAPA DE MORTERO EN EL MURO DE LADRILLOS

Con la paleta, colocar la primera capa de mortero a lo largo de la base del cimiento. Agregar un poco más de esos 1.5 – 2 cm ya que se apretará el ladrillo ligeramente al colocarlo.

PASO 11: PRIMER LADRILLO EN EL MURO DE LADRILLOS

Colocar el primer ladrillo y presionarlo ligeramente, luego utilizar el nivelador para verificar que esté nivelado con el suelo y luego verificarlo con la cuerda guía.

Retirar el mortero excedente de la junta y usarlo para los siguientes ladrillos. Cuando se este seguro/a de que el primer ladrillo está bien colocado, colocar un poco de mortero para los siguientes 2 o 3 ladrillos.

PASO 12: RECUBRIMIENTO

Tomar una porción de mortero y recubrir el extremo del siguiente ladrillo, que empujará contra el primer ladrillo. Se debe colocar una capa de mortero uniforme del grosor que se ha comentado.

Presionar contra el primer ladrillo al ponerlo en su lugar y utilizar la cinta métrica para asegurarse de que está a la distancia correcta.

PASO 13: PRESIONAR EL LADRILLO LIGERAMENTE

Presionar sobre la capa de mortero que se colocó en la base. Utilizar el nivelador para asegurarse de que los ladrillos estén alineados y a una altura uniforme. Presionarlos ligeramente para asegurarse de que estén colocados de manera perfecta.

Después retirar con la paleta el mortero excedente a medida que se avanza, porque al presionar los ladrillos para obtener las juntas de 1.5 – 2 cm, el mortero comienza a sobresalir.

PASO 14: FILA DEL MURO DE LADRILLOS

Seguir agregando ladrillos hasta que se haya terminado la fila. Continuar colocando de la misma manera, cubrir la base y un lado con mortero, presionar y revisar la alineación con el nivelador hasta que se haya completado la primera fila o hilada.

Se tiene que ser meticuloso y utilizar el nivelador y la cinta métrica con casi todos los ladrillos.

PASO 15: SUBIR LA CUERDA GUÍA AL SIGUIENTE MARCADOR

Se tiene que mover la cuerda cada vez que se avanza a una nueva fila, de manera que se pueda saber cuál es la altura a la que debe llegar.

PASO 16: COMENZAR LA SIGUIENTE FILA CON LA MITAD DE UN LADRILLO EN CADA EXTREMO

Se puede cortar con la paleta o un martillo. De esa forma, se evita que la siguiente fila quede exactamente encima de la anterior con las juntas alineadas. Se necesita que la junta quede corrida o a rompejunta, y para ello, hay que colocar mortero en el medio ladrillo y poner en posición, y luego colocar un ladrillo entero al lado de la manera usual.

Repetir en el otro extremo de la pared, de manera que ya se haya puesto en posición medio ladrillo y un ladrillo entero a cada lado.

PASO 17: MANTENER LA ALINEACIÓN DEL MURO DE LADRILLOS

Para mantener la alineación, se tiene que construir los extremos de la pared hasta una hilada arriba de la que se esté trabajando, de manera que parezca que hubiera una escalera en los extremos de la pared. Luego, completar la fila inferior, volver a construir los extremos de una hilada más arriba y continuar así hasta llegar a la parte superior.



D4.2 - Intelligent exoskeleton with intention prediction prototype

Utilizar la cuerda guía junto con el nivelador para asegurarse de que los ladrillos estén alineados y a la altura correcta. Las barras de medición ayudarán a colocar los ladrillos de los extremos, ya que estos se alinearán de manera exacta con las marcas colocadas en el extremo de la pared.

Continuar construyendo la pared desde los extremos hacia dentro. Los extremos de la pared deben estar contruidos hasta la hilada encima de la fila en la que se esté trabajando. Esto es importante, especialmente si la pared tiene columnas en cualquiera de los extremos. El procedimiento es el mismo en cada fila:

- Mover la cuerda guía.
- Aplicar el mortero.
- Presionar un ladrillo en cualquiera de los extremos de la pared con ayuda de la cuerda guía y el nivelador para asegurarse de que estén a la altura correcta.
- Hacer lo mismo en la fila que esté encima de la que se construya en el momento.
- Medir, colocar el mortero y construir la fila que esté más abajo (completar las hiladas)
- Repetir el proceso en la siguiente fila.

PASO 18: RELLENAR CON MORTERO

Rellenar con mortero cualquier parte de la pared que lo necesite. Utilizar la paleta de albañil para rellenar cualquier parte o espacio en las juntas y asegurarse de que esté uniforme.

Esperar aproximadamente 45 a 60 minutos antes de continuar, ya que el mortero tiene que estar ligeramente endurecido antes de proseguir.

PASO 19: ACABADO PROFESIONAL AL MORTERO

Utilizar un llaguero para darle un acabado profesional al mortero. Los llagueros son pequeñas herramientas que ayudan a obtener ese acabado curvo y profesional en las juntas de la pared.

Presionar de manera firme la herramienta sobre las juntas y deslizarla por el mortero para dejar un acabado perfecto al muro de ladrillos que se acaba de levantar.

A.3. EVALUACIÓN DE RIESGOS

NORMAS BÁSICAS DE SEGURIDAD

- Las zonas de trabajo serán limpiadas de escombros (cascotes de ladrillo) periódicamente, para evitar las acumulaciones innecesarias.
- Se prohíbe balancear las cargas suspendidas para su instalación en las plantas, en prevención del riesgo de caída al vacío.
- El material cerámico se izará a las plantas sin romper los flejes (o envoltura de P.V.C.) con las que lo suministre el fabricante, para evitar los riesgos por derrame de la carga.
- El ladrillo suelto se izará apilado ordenadamente en el interior de plataformas de izar emplintadas, vigilando que no puedan caer las piezas por desplome durante el transporte.
- La cerámica paletizada transportada con grúa se gobernará mediante cabos amarrados a la base de la plataforma de elevación. Nunca directamente con las manos, en prevención de golpes, atrapamiento o caídas al vacío por péndulo de la carga.
- Se prohíbe concentrar las cargas de ladrillos sobre vanos. El acopio de palets, se realizará próximo a cada pilar para evitar las sobrecargas de la estructura en los lugares de menor resistencia.
- Los escombros y cascotes se evacuarán diariamente mediante trompas de vertido montadas al efecto, para evitar el riesgo de pisadas sobre materiales, ubicándose aquellas según plano.
- Se prohíbe lanzar cascotes directamente por las aberturas de fachadas, o huecos interiores.

RIESGOS MÁS FRECUENTES EN ALBAÑILERIA

- Absorción por vías respiratorias: polvo en operaciones de corte de ladrillos
- Golpes y cortes con objetos y herramientas manuales.
- Dermatitis por contactos con el cemento.
- Partículas en los ojos.
- Sobreesfuerzos.

EQUIPOS DE PROTECCIÓN INDIVIDUAL EN TRABAJOS DE ALBAÑILERIA

- Casco de polietileno CERTIFICADO.
- Guantes de Cuero o de P.V.C. o de goma.
- Botas de seguridad.
- Cinturón de seguridad, Clases A y C.
- Trajes para tiempo lluvioso.
- Gafas antiproyecciones
- Cascos para trabajos con ruido



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