Ref. Ares(2020)628963 - 01/02/2020

Deliverable Title	D5.1 Description of the Facilities: Building, spaces and commercial systems available
Deliverable Lead:	CSIC
Related Work Package:	WP5: Benchmarking facilities
Related Task(s):	T5.1 Setup of the two facilities
Author(s):	Jinoh Lee, Guillermo Asín, Nikos Tsagarakis, Diego Torricelli, Antonio Oliviero
Dissemination Level:	Public / Confidential
Due Submission Date:	31.12.2019
Actual Submission:	31.01.2020
Project Number	779963
Instrument:	Research and Innovation Action
Start Date of Project:	01.01.2018
Duration:	48 months
Abstract	This deliverable includes the concept design of the facilities for humanoids and wearable robots, as a result of T5.1, and the list of the testbeds to be integrated, as preliminary results of T5.2 (being many of the testbed still in development phase).

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

Versioning and Contribution History

Version	Date	Modified by	Modification reason
v.01	20/12/2019	Guillermo Asín	First version
v.02	15/01/2020	Jinoh Lee, Guillermo Asín, Nikos Tsagarakis	Second version
v.03	31/01/2020	Diego Torricelli & Antonio Oliviero	Internal peer-review and approval

Table of Contents

1 Executive Summary

The main goal of WP5 is preparing two facilities, one for humanoids in Genova (IIT), and one for wearable robots in Madrid (CSIC), in order to host the selected third parties from FSTP-2 Call during the validation trials. The facilities should be fully operative at month 36 of the project (December 2020). In the first 24 months of the work plan, the tasks T5.1 and T5.2 have been active. T5.1 mainly aimed to define the initial concept designs of two facilities, i.e. the spaces needed to allocate the different test benches. T5.2 aimed at select and integrate the test benches developed from the consortium and third parties participating in the FSTP-1 action. This deliverable included the concept design of the facilities (as a result of T5.1) and the list of the testbeds to be integrated (as partial results of T5.2, being many of the testbed still in development phase). The concept design here presented is being improved by iterative design process and discussions with EUROBENCH partner.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

2 Facility for Humanoids

2.1 Concept design

2.1.1 Definition and organization of spaces

The facility for Humanoids will be established at Istituto Italiano di Tecnologia (IIT) in Genoa, Italy. In autumn 2018, IIT opened the new robotics centre, called "Center for Robotics and Intelligent Systems (CRIS)" at San Quirico, Genova, Italy, as seen in Figure 1. CRIS will be totally refurbished to host state-of-art laboratories and testing facilities and robotics research lines will share a common space to foster collaboration and integration (Figure 2).

Figure 1: The location of the IIT-CRIS

Figure 2: The outside view of the building of IIT-CRIS.

The workspace for the benchmarking facility in IIT-CRIS is being planned to consist of an indoor area and a storage area, as shown in Figure 3. The indoor space is expected to be 90m2, and the storage area to be maximum of 200 m2 in total. Subject to outdoor area arrangement outside the CRIS building, IIT is considering to evaluate the possibility to establish also an outdoor space where outdoor trial activities can be performed. The size of this external area will be clarified in the future. In the case that the outdoor area will be established to effectively arrange the benchmarking workspace, the indoor and outdoor areas will be connected with an accessible pathway. Therefore, equipment, testing robots, and some portable devices and testbeds can be easily transferred from one to the other places.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

Figure 4 illustrates the initial concept design of the benchmarking facility for the indoor area. The testing track with curved and straight path will be indicated. The width of the track will be approximately 1.5m (as the minimum width) which is sufficiently large to place the portable test benches such as door, stairs, obstacles, and disturbance devices.

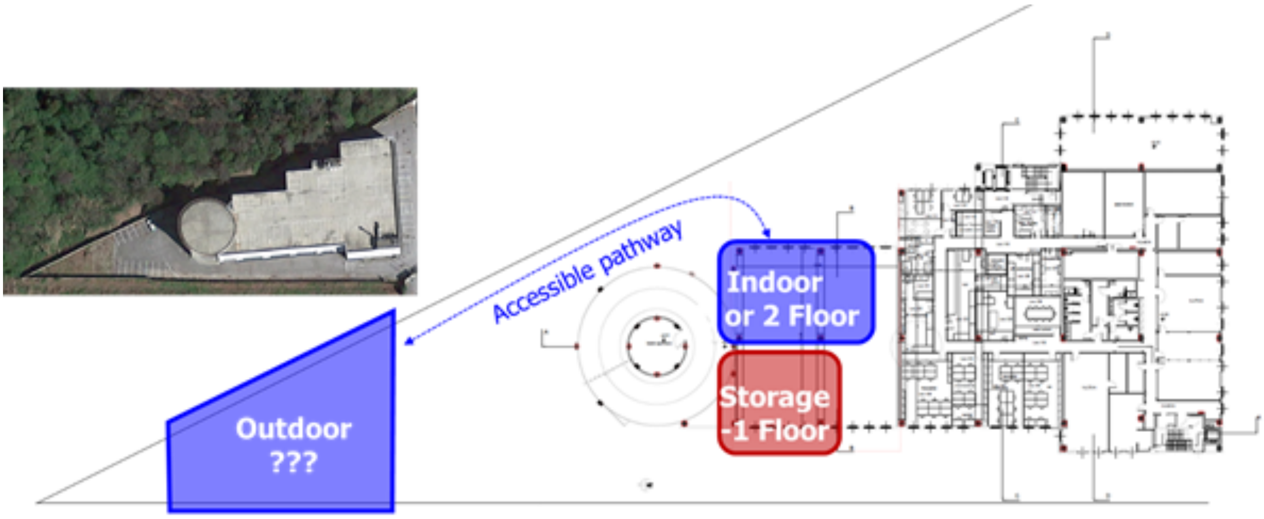
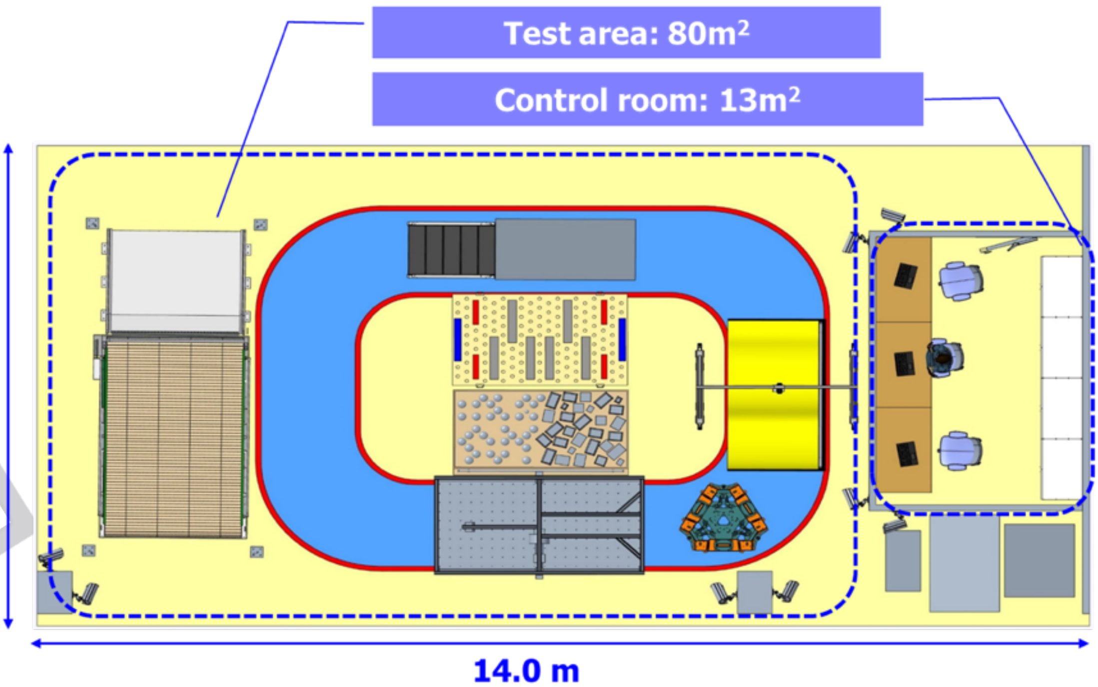


Figure 3: The workspaces available for the benchmarking facility for humanoids.

A large gantry system will be installed to enable the safe execution of experiments by supporting and carrying the robotic platforms in the testing track. The gantry system will provide two independent hanging interfaces permitting the simultaneous support and operation of two robotics platforms.



This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

Figure 4: Concept Design of the indoor area

Monitoring cameras will be placed at fixed locations to continuously record the events in the benchmarking area, while portable camera system (also including a high-speed camera) will be also be available for the recording of dynamic motion transients. The inner space of the testing track will be equipped with a large treadmill testbed, where the motion capture system can be installed to collect the data from the treadmill test. There will be also a general testing area in the inner space, where any portable testbeds and devices, e.g., a force plate, can be installed and motion capture system can be also mounted. This concept design will be further improved and detailed by the iterative design process and discussions with EUROBENCH partners.

A control station area will be allocated where the facility IT equipment enabling the execution monitoring and logging of the experimental data will be installed. A draft 3D mock-up of the humanoid robot facility space is shown in Figure 5.

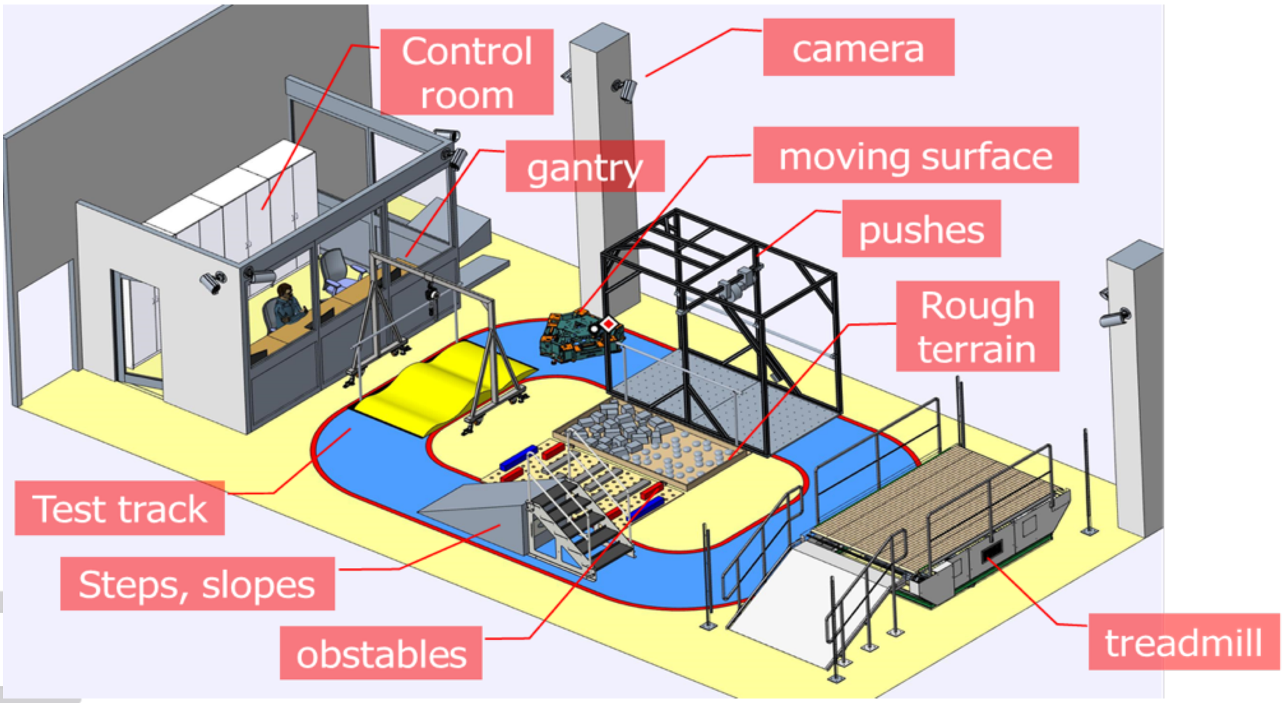


Figure 5: 3d CAD and real space

The space of the humanoid benchmarking facility is currently under preparation at the IIT Centre of Robotics and Intelligent Systems, (CRIS). The renovation of the facility space is expected to be completed by June 2020 making the area available for the installation equipment. Figure 6 shows some images of the facility space in the CRIS building currently under preparation.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

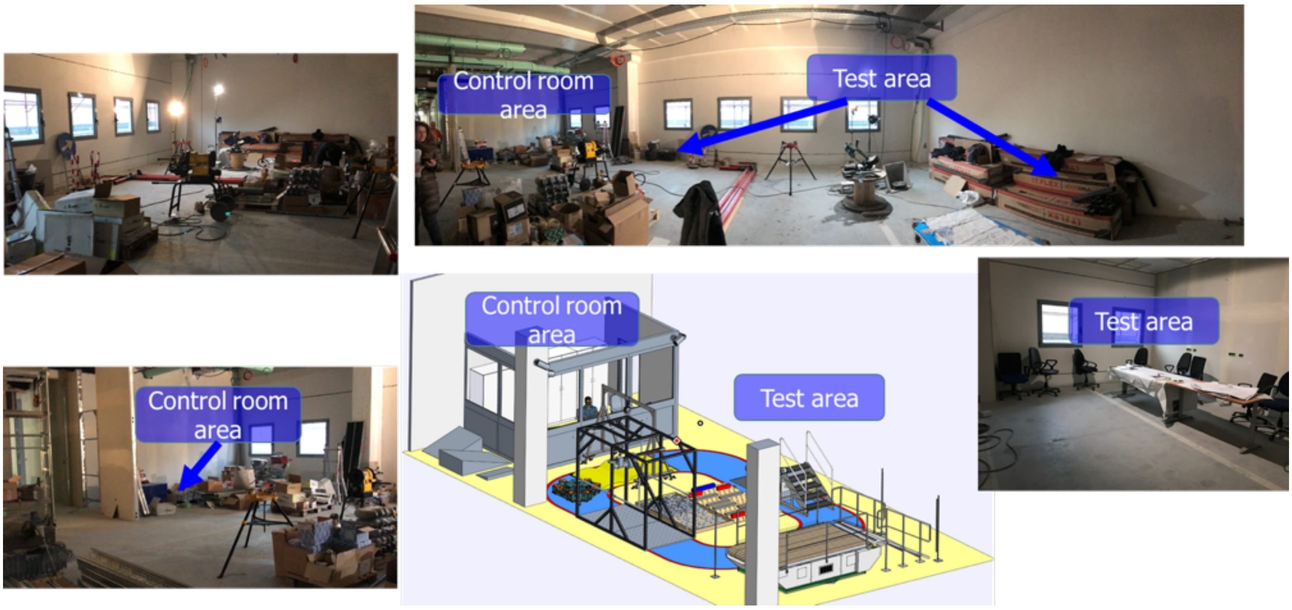


Figure 6: Images of the facility space (under renovation) at the IIT Centre of Robotics and Intelligent Systems, (CRIS)"

2.1.2 Technical requirements

The general requirement for the humanoids facility is summarized as the result of T2.1-T2.4:

- An experimental lab space of approximately 90-100m^2 on benchmarking of robot systems with specific focus on legged mobile manipulation platforms.
- The facility should be instrumented and equipped with state-of-the-art devices and testbeds, allowing one to measure the robot ability levels on a rigorous, quantitative and replicable way.
- A control area enabling the execution of benchmarking trials with the available robotic platforms and the logging of experimental data.
- A parking space for the robotic platforms.
- A dedicated storage area for the not used testbeds and equipment.

The facility shall enable the execution of the following benchmarking scenarios:

- Rough terrain negotiation, including obstacles, irregular hard surfaces, and soft materials (e.g. mattress).
- Stairs climbing and descending.
- Slopes climbing and descending, including different degrees of elevation.
- Sit to stand and stand-to-sit.
- Balancing against disturbances (pushes and moving ground) during standing or walking.
- Moving in narrow spaces.
- Door opening and closing.
- Pushing a shopping cart.

The list of the facility equipment should include:

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

- Instrumented disturbance devices to provide controlled perturbations to legged mobile manipulation platforms, for benchmarking of balance performance.
- High-end treadmill with lateral and sagittal tilting capacity and variable speed to facilitate additional benchmarks of balance, such as gait initiation.
- An instrumented door.
- An instrument robotized shopping cart.
- A gantry support system to provide independent support of two robotic platforms.to ensure safety and stability during postural and walking tasks.
- A visual tracking system.
- A camera system capable of recording experiments of different kinds.
- Control PC stations with the necessary network connectivity enabling the execution of benchmarking trials and the logging of data.

2.2 Testbeds and equipment

2.2.1 Testbed developments in FSTP-1

'Treadmill' testbed

This testbed is a motorized treadmill with variable speed and 2DOF pitch/roll inclination (Figure 7). It will allow the execution of experimental locomotion and balancing trials as well the execution of long time endurance tests under variable speed and inclination settings. It allows an inclination of 10º pitch and 5º roll.

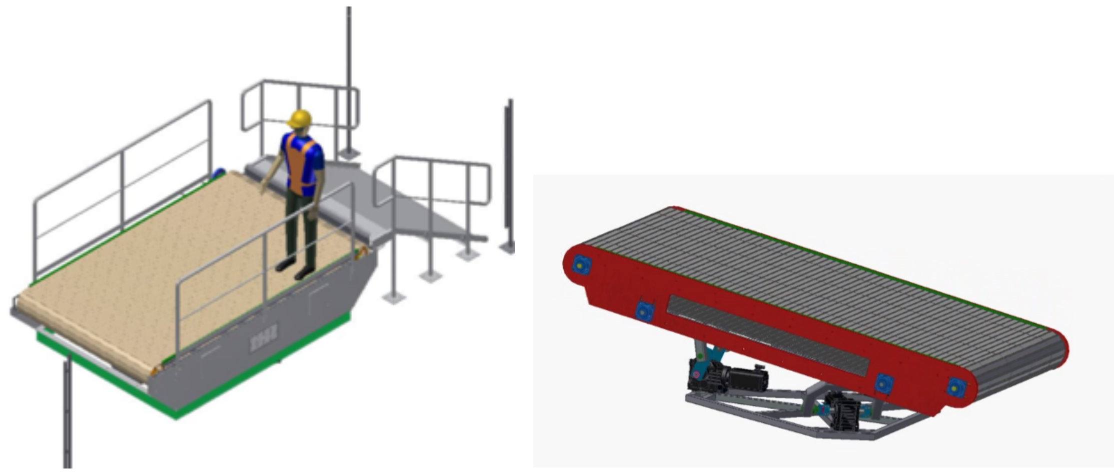


Figure 7: The Treadmill testbed CAD

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

'COMTEST' testbed

This testbed is a moving surface disturbance device, designed to test human and humanoid posture control and balance under perturbed conditions, addressed to the scenario Standing on Moving Surfaces. The system includes a moving support surface used to provide the perturbation (Figure 8), an innovative body tracking system suitable for robots, humans and exoskeletons, a control software and a set of predefined perturbations.

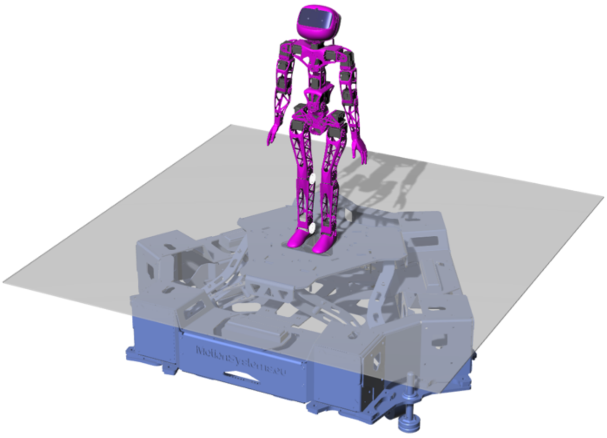


Figure 8: The 'COMTEST' testbed CAD

'DYSTURBANCE' testbed

This testbed is a perturbation system to be used for the systematic characterization of walking robots and locomotion systems. The proposed system realizes a system capable of exerting a given desired force or impulse perturbation. The system integrates position and force sensors to be able to fully characterize the disturbance that we are applying to the walking system. It integrates a motorized shaft, to be able to control the exertion of forces both in the static and dynamic cases. The system is implemented in the form of a moveable portal for easy integration with other experimental rigs.

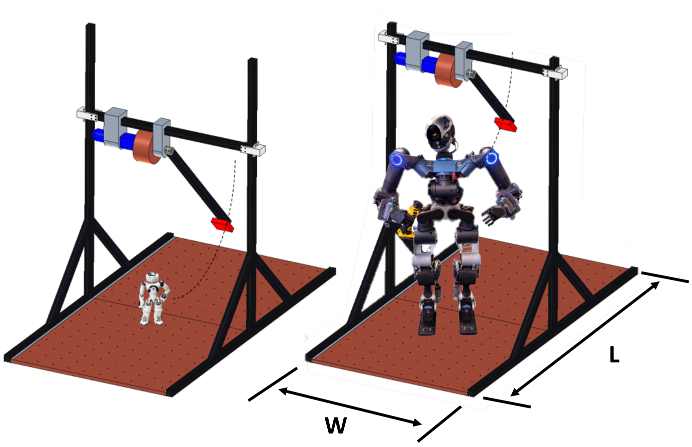


Figure 9: The "DYSTURBANCE' testbed schematic representation

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

'MADROB' testbed

This testbed is an active door that, while maintaining all the features of a standard manually-operated hinged door, enables quantitative characterisation of the capability of a robot to interact with it by precisely measuring the forces applied by the robot and the movement of the door. The active door can also apply controlled torque to the door panel to manipulate its physical characteristics as perceived by the robot (e.g., moment of inertia, friction) or to introduce controlled disturbances in its motion (simulating obstructions, effect of wind, push by another user).

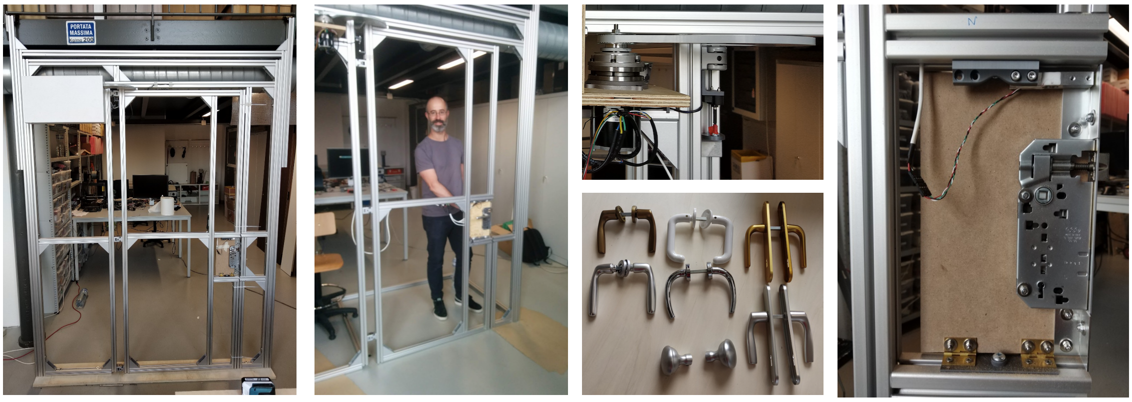


Figure 10: The "MADROB' prototype

'BEAST' testbed

This testbed is an active shopping cart that, while maintaining all the features of a standard trolley, enables quantitative characterisation of the capability of a robot to manoeuver it safely and effectively. The BEAST cart can measure its own acceleration, the geometric relationship with surrounding obstacles (distance and collisions) and the forces applied by the robot to its handle. Additionally, the active trolley can introduce repeatable disturbances in its dynamic behavior by applying torque to the wheels, allowing simulation of real-world effects such as friction, irregular floors or wheel obstructions.

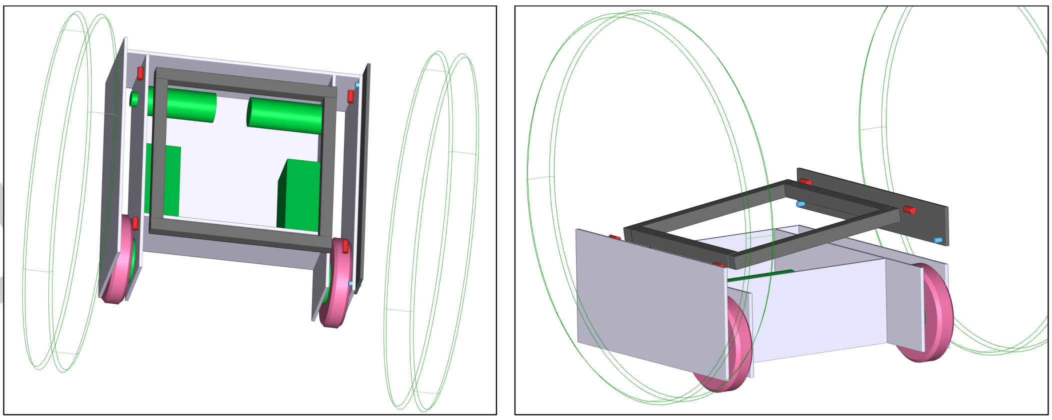


Figure 11: The "BEAST' motorized mechanism concept

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

2.2.2 Internal Testbed developments

In addition to the testbeds that that will be provided through the FSTP1 call a number of additional testbeds are under development internally and will be included in the humanoid facility. These currently include the followings.

Narrow passage panels

This testbed development target to produce a set of modular panel components that can be linked together to create narrow passages of arbitrary paths. The passage walls will be composed by wooden plates interconnected through a number of assembly interfaces permitting the regulation of the angle between to subsequent panels, Figure 12.

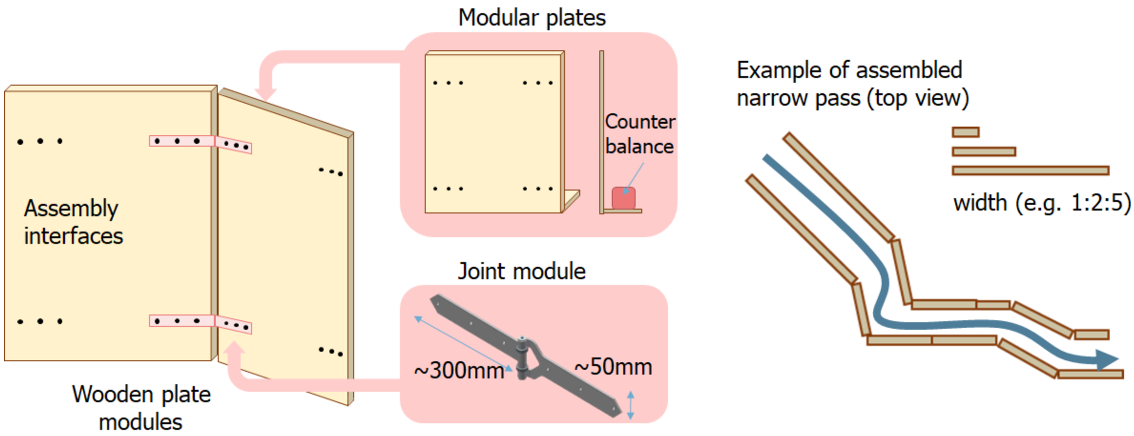


Figure 12: Narrow passage panels

Terrain slopes

This testbed will include a number of terrain slope parts that will permit the composition of terrain profiles with variable inclinations. The initial family of parts for this testbed will consider triangular profiles of different size and inclination and parallelepiped parts of different length, Figure 13.

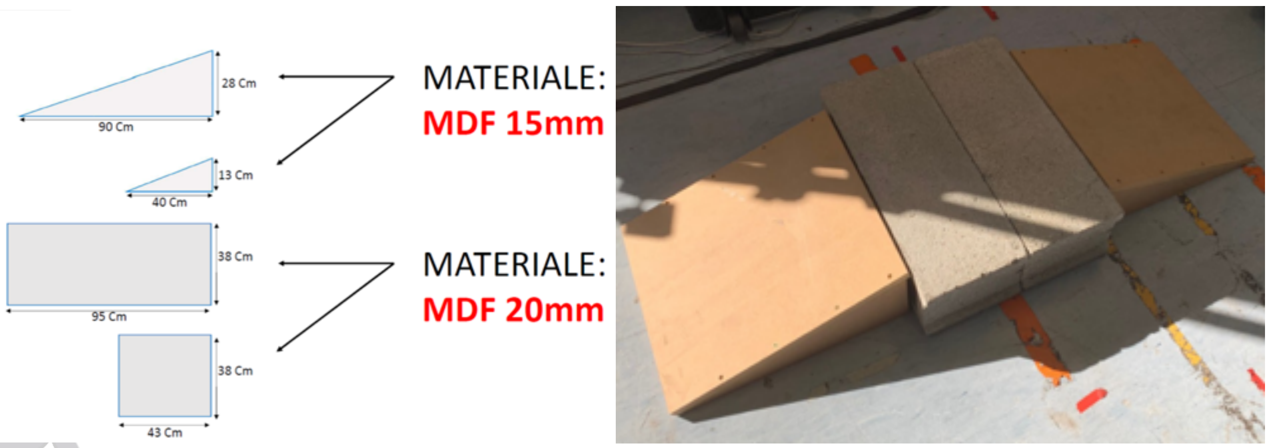


Figure 13: Prototypes of terrain slopes.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

2.2.3 Other systems purchased or already available

Additional equipment in the humanoids facility will include an X-sense wearable suit for whole body-tracking, a force plate platform and a safety gantry system and several robotic platforms including the COMAN humanoid, the CENTAURO quadruped platform and the iCub humanoid, Figure 14.

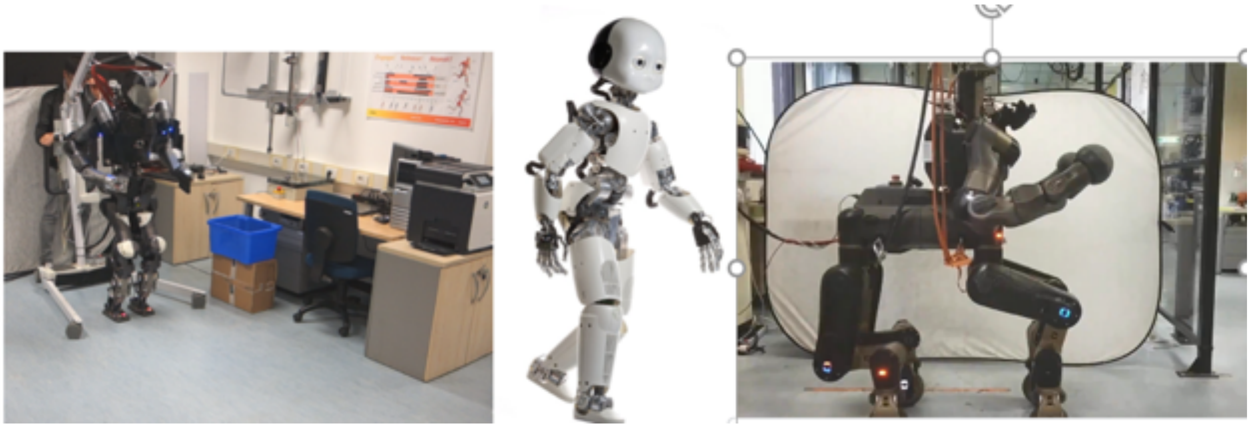


Figure 14: Prototype legged robotic platforms that will be available in the humanoid facility.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

3 Facility for Wearable robots

3.1 Concept design

3.1.1 Definition and organization of spaces

The facility for Wearable Robots (WR) will be located in Brunete, at 27 kilometres to the west of Madrid (Spain).

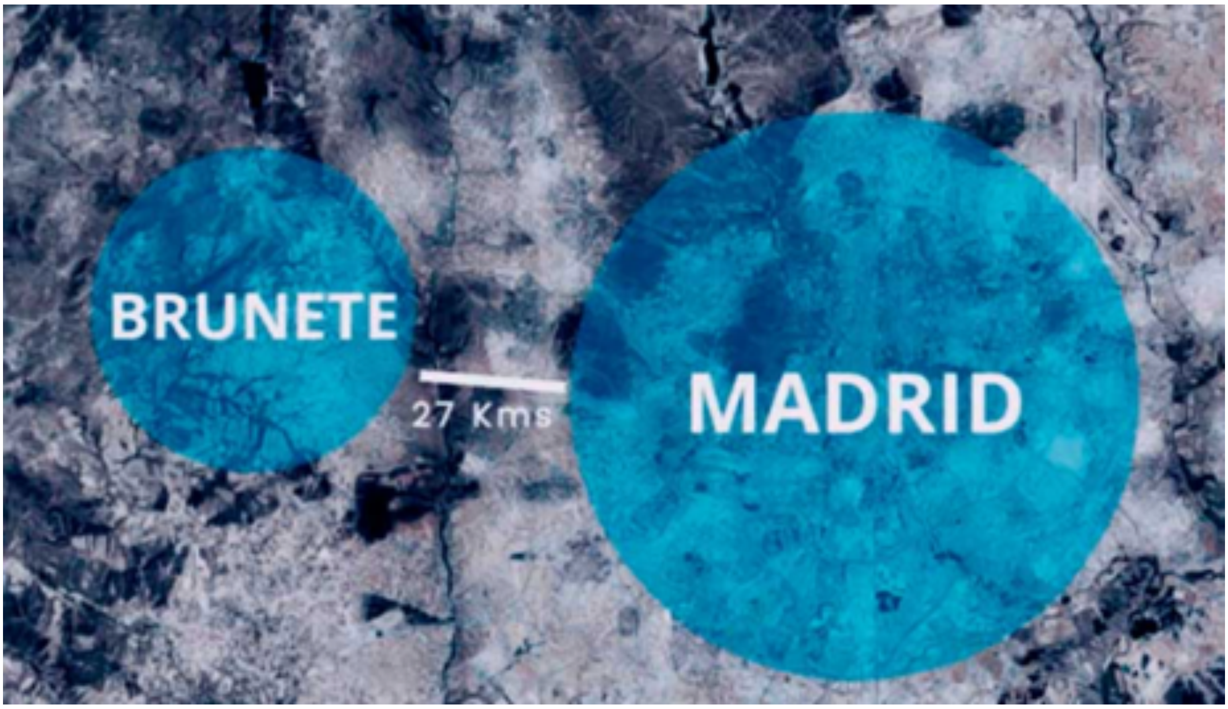


Figure 15: Brunete location

The building will be an extension of the "Los Madroños" Hospital (see Figure 16), as a means to have easy and fast access to patients and clinicians (end-users) near the facility. The staff of the facility will be composed of technicians, engineers and clinicians with the expertise in testing robotic technologies. This clinical institution has a well-established network with other Hospitals and Universities, as well as contacts with legal entities able to support and maximise the business model available. The facility will be located at the left of the main facade of the Hospital (South East). It will be comprised of three floors (see Figure 17,Figure 18Figure 19), with several medical services (neural rehabilitation gym and R&D space oriented towards neural rehabilitation). The facility lab for WR testing will be located at the ground floor.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

Figure 16: Facility location with respect to the hospital.

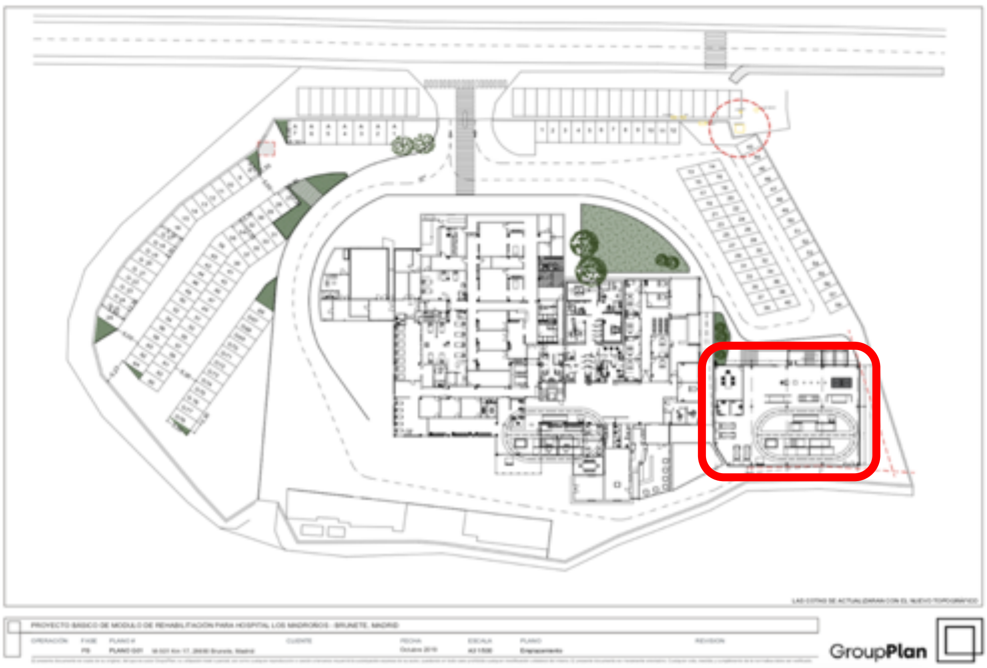


Figure 17: Layout of the location of the facility

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

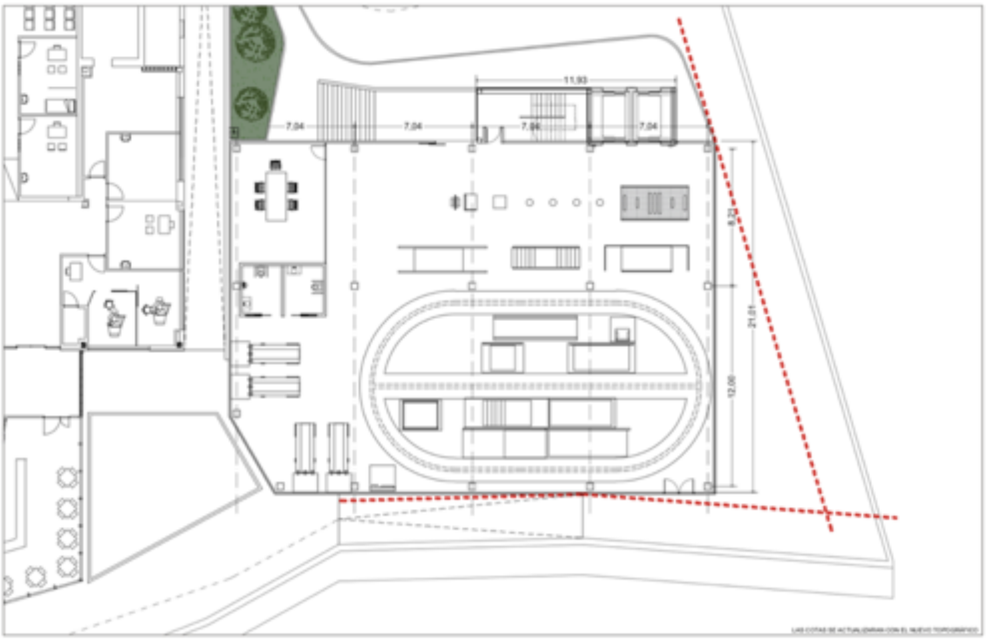


Figure 18: Facility layout

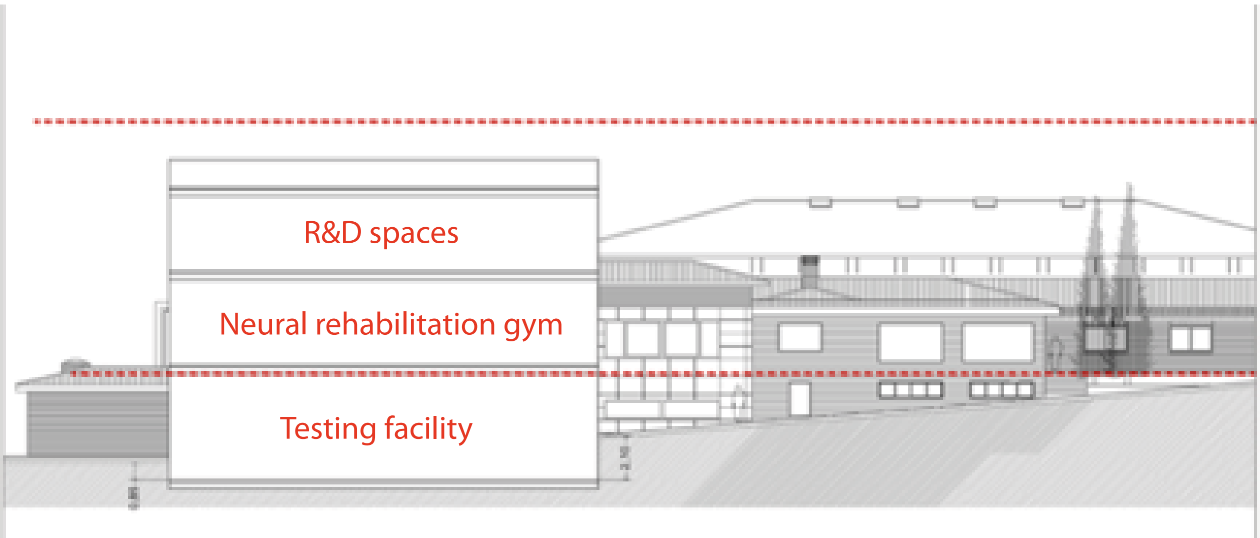


Figure 19: Side view sketch of the facility

The space available at the ground floor (testing facility) will be divided in three subspaces (Figure 20): technical area (150 m^2), Cybathlon area (200 m^2) and EUROBENCH testbeds area (300 m^2). The technical area is devoted to provide a space for the staff and external technicians. Cybathlon area will mimic the homonymous competition testbeds. The EUROBENCH area will be comprised of a circuit with all the testbeds that are being developed by the consortium and all the TPs from FSTP-1, which are further explained in the next section.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

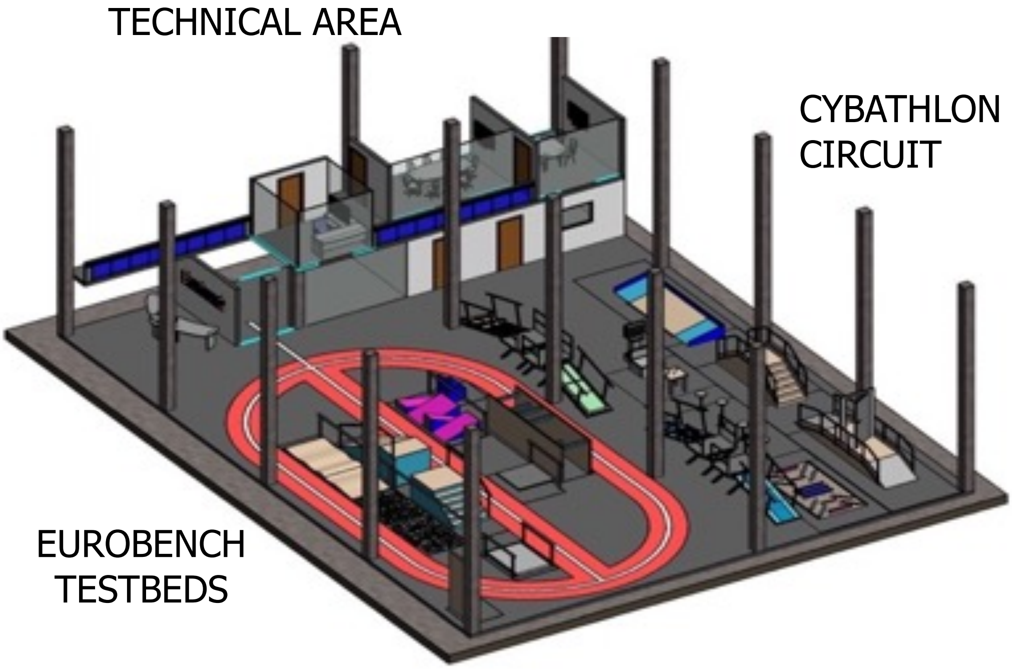


Figure 20: 3D CAD of the facility.

3.1.2 Technical requirements

The technical requirements for the WR facility are:

- An indoor area of around 600 m^2.
- An oval circuit to allow continuous locomotion trials without the need of turns.
- A rectilinear path to perform classic gait analysis measurements.
- A rectangular area of approximately 10x10m covered by optical motion capture system (Vicon). In this area, it is intended to place most of the testbeds developed by Third Parties. In the future, it is envisioned that the area will be enlarged, with the addition of more cameras.
- A Cybathlon area, which will include all the testbeds needed to replicate the Cybathlon exoskeleton or lower limb prosthesis races.
- A preparation area to prepare the subjects before the trial, in respect of privacy.
- A technical workshop area of approximately 40 m^2.
- A meeting area of about 50 m^2.
- A control room, in which servers and other private information (e.g. informed consent sheets) will be secured.
- Different exoskeleton robots, e.g. the H3 provided by Technaid.
- Body weight support/safety harness systems. The specific solution has to be defined yet (different companies have been already contacted).
- Approximately 15 boxes in the floor of the facility, containing 220 VAC supply, LAN Ethernet connection, and USB charging ports (optional).
- WiFi router supporting UDP Multicast.
- Some triphasic power plugs (380 VAC, more than 750W).

- Several 5 VDC and 32-48 VDC plugs.
- The area should be free of any sunlight, to allow photogrammetry systems work properly.
- Non-reflexing floor and walls to avoid reflections on the photogrammetry system.
- Remote access to the whole facility systems, to permit remote monitoring and support for software infrastructure.

The basic personnel profiles needed to provide services are: engineers (1 senior, 1 junior) and one/two physiotherapist(s). The engineers will be in charge of: running the equipment, solving technical problems, performing the data analyses, solving synchronization issues (ROS experts), managing the database. The physiotherapist(s) will be in charge of instrumenting the patient (e.g. marker placement) and assisting the patient (for donning and doffing of exoskeletons, support during the trials).

3.2 Testbeds and equipment

3.2.1 Testbed developments in FSTP-1

'BEAT' testbed

This testbed addresses the benchmarking scenario "Walking/Standing on a moving surface". The project aims to adapt consolidated equilibrium assessment techniques to benchmark the exoskeleton efficacy in assisting both static and dynamic body balance. The testbed is equipped with an upgraded version of the 3-DOF parallel robot Roto.BiT 3D, impedance controllable and capable to rotate the foot support along three axes (Figure 21). It is also capable of measuring the full foot support reaction, and the feet pressure distribution. The device is capable to support the entire weight and inertia of the subject wearing the exoskeleton.

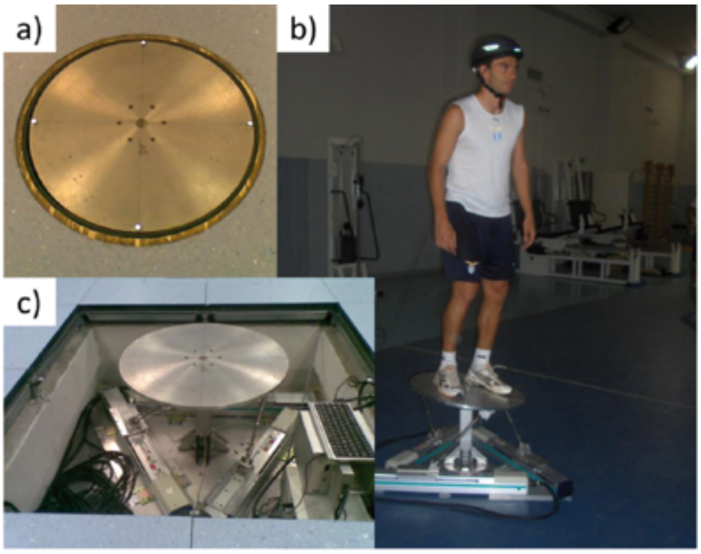


Figure 21: BEAT testbed device. Subfigure a) shows the plate where the user stands; b) shows a user on the device; and c) presents the integration in the floor of the testbed.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

'BENCH' testbed

This testbed is focused on developing one integrated system for the assessment and benchmarking of the sit-to-stand gesture in intact and impaired individuals. It represents an integrated technical solution for evaluating contact forces, kinematics, kinetics and neuromuscular correlates of sit-to-stand through the integration of fixed (force plates and force sensors) and wearable (IMUs) sensors. It mainly consists of an instrumented chair/ground apparatus with two 6-DoF force plates for the measurement of interaction forces, instrumented handrails and a set of body-worn IMUs.

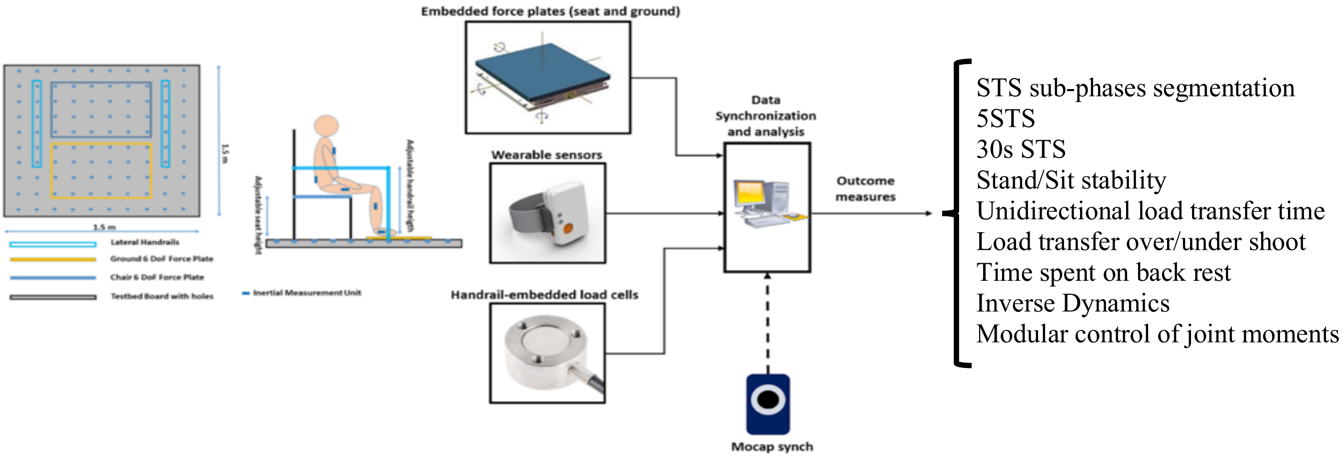


Figure 22: BENCH testbed. The figure shows the layout of the testbed (left). In the middle, there is a schematic of the testbed task. On the right, all the components that comprise this testbed are depicted.

'BenchBalance' testbed

This testbed is a device able to apply well defined pushing perturbations for benchmarking balance capabilities of wearable robots. It integrates two elements (Figure 23): (1) a portable disturbance generator equipped with different sensors, which can provide and quantify well-defined pushes to the human upper body during both, standing and walking conditions; and (2) a smart vest with a position system detector, which determines the location of the generated disturbance in relation to the human wearing the exoskeleton.

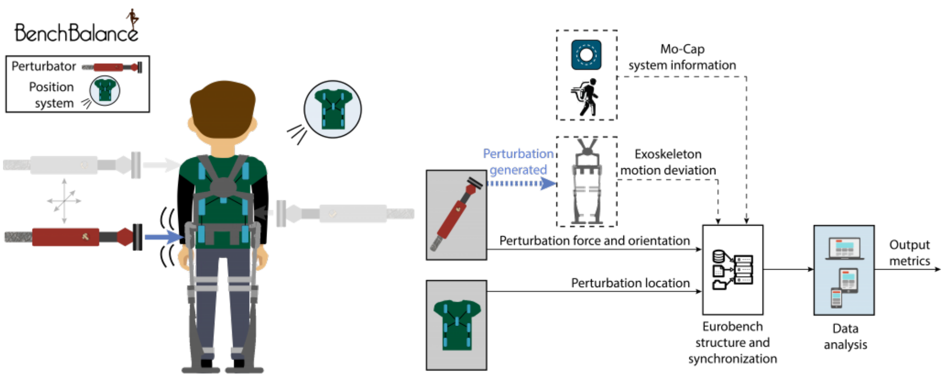


Figure 23: Schematic view of the BenchBalance testbed.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

'BeStABle' testbed

This testbed is focused on inducing perturbations and to register the resulting subject responses. The testbed is made of two elements (Figure 24): the wearable GyBAR which can induce torques to the upper body, and the BAR-TM, a treadmill-based device that can apply lateral forces to the hip. Thus, the objective of this testbed is to develop experimental protocols and outcome measures to assess the ability to recover from perturbations and balance, using an instrumented treadmill, together with IMUs and a projection system for virtual obstacle production.

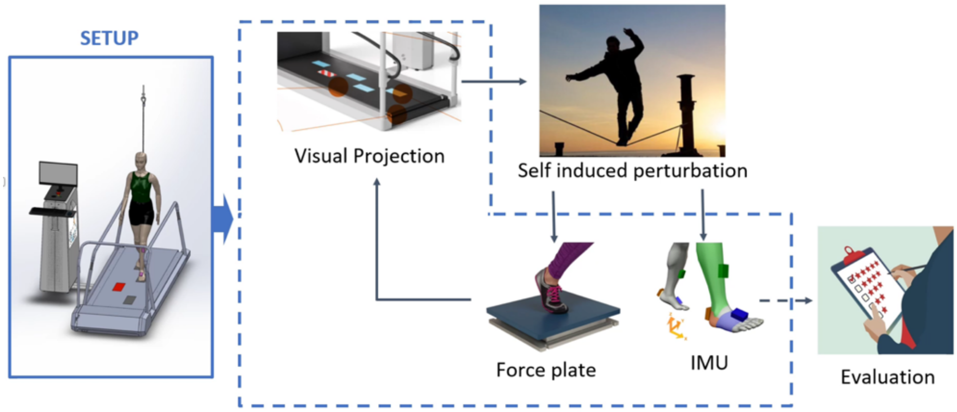


Figure 24: BeStABle testbed framework schema.

'BULLET' testbed

This testbed aims at measuring full body joints' reactions, including upper limb joints, during walking with crutches. The testbed integrates two elements (Figure 25): a pair of instrumented crutches able to measure the load applied by the user, the orientation, and the position of the foot via a ToF camera; and an automated volume scanning system (based on portable ToF cameras) to measure the body segments center of mass, inertia and mass using the volumetric information acquired.

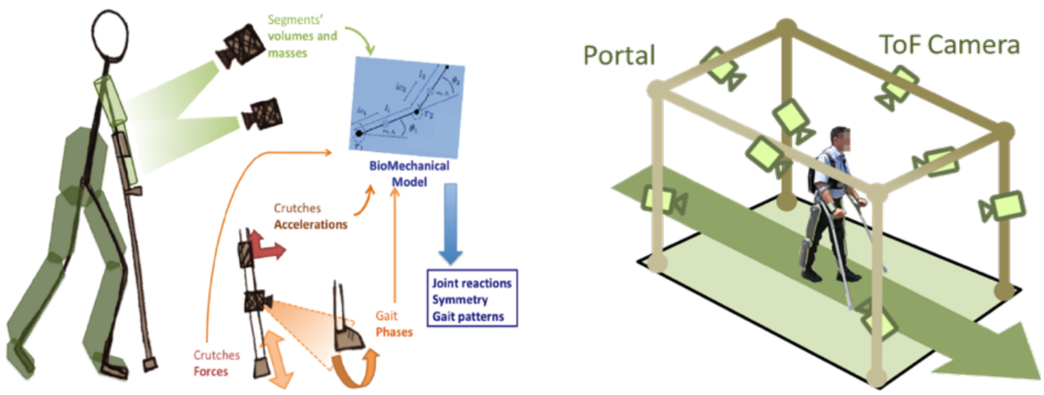


Figure 25: Schematic view of the BULLET testbed.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

'STEPbySTEP' testbed

This testbed (Figure 26) is a modular and sensorized reconfigurable staircase for lower-limb exoskeletons benchmarking. The inclination of the staircase can be easily adjusted as well as the height of the steps. The staircase is provided at the upper end with a height-adjustable platform, allowing for turning, and with handrails at both sides for safety reasons. This testbed includes load cells for the handrails, two force platforms embedded in the stairs. A motion capture system and a physiological-signal measurement system (e.g., heartrate and EDA measurement) will be integrated in the testbed.

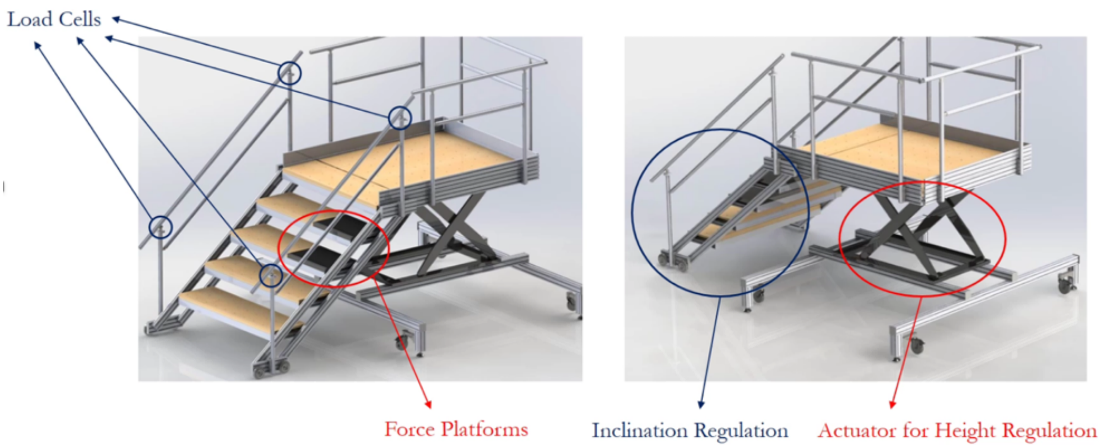


Figure 26: STEPbySTEP testbed 3D model.

'TestEd' testbed

This testbed is able to variate the distance between two walls, as well as providing the possibility to add obstacles and handling bars. It can mimic several scenarios, e.g., obstacles on the floor or a moving bus cabin. The testbed also provides information on the metabolic cost. It comprises a questionnaire at the end, and a digitized version of the Borg scale.

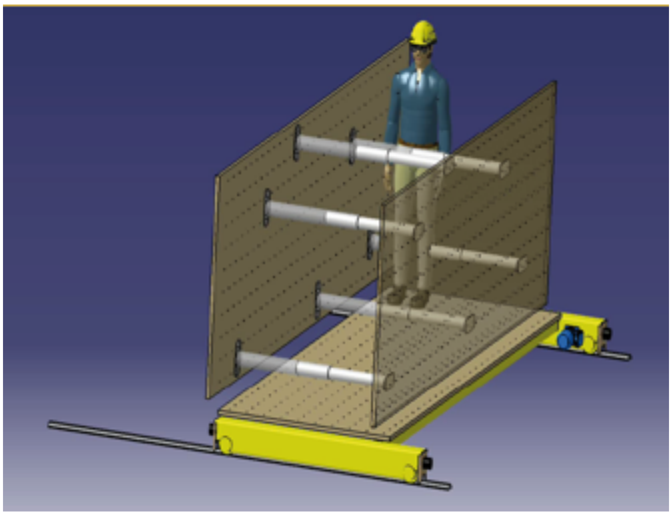


Figure 27: TestEd testbed 3D model, with avatar undergoing the task.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

3.2.2 Internal Testbed developments

'4-in-1' testbed

The consortium is currently developing a 4-in-1 testbed (Figure 28), that provides the ability to 1) manage different slopes, 2) provide irregular terrains, via 48 changeable modules with different heights and slopes, and commercial TerraSENSA modules, 3) provide obstacles and 4) provide soft terrains. The system has two lateral bars, adjustable height, to provide safety to the user.

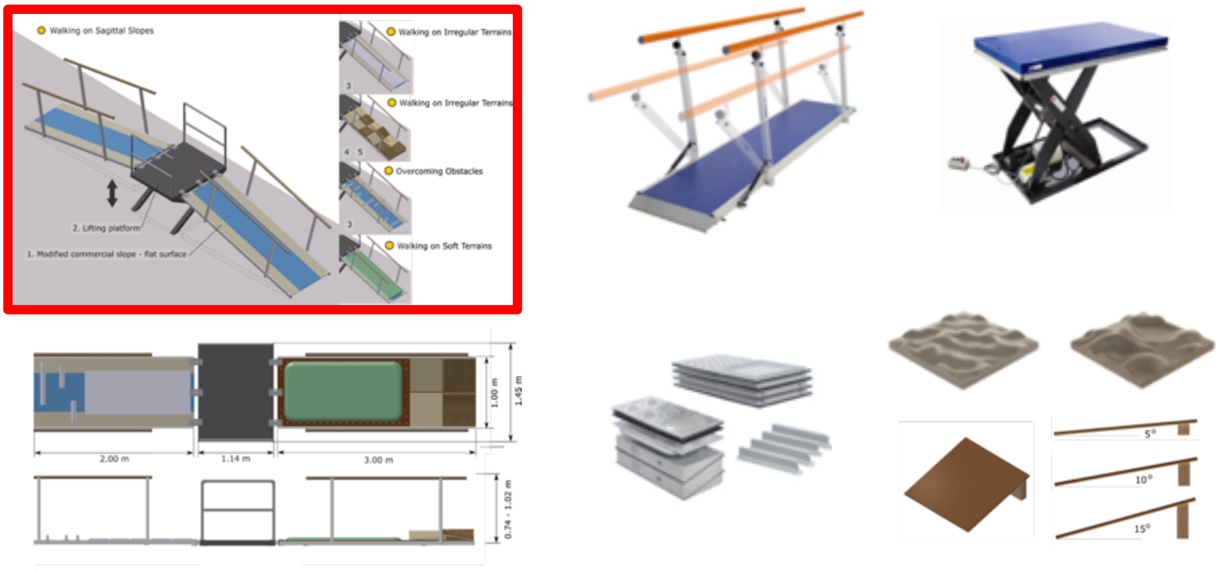


Figure 28: The 4-in-1 testbed.

'3D-grid' testbed

The consortium also developed a testbed for testing manipulation skills testing while standing. The mechanical structure consists of a fixed frame and four mobile parts (Figure 29). The fixed frame is composed of three vertical bars connected to four horizontal bars, creating two "walls" at 90º. Two additional bars are used to close the square at floor-level in order to give more consistency to the structure. The mobile parts are four sliding bars that fit in the fixed frame, two bars per wall that, thanks to a guiding system, can be horizontally moved. On top of each sliding bar there is a wooden shelf where a box should be left between the lifting and lowering tasks.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

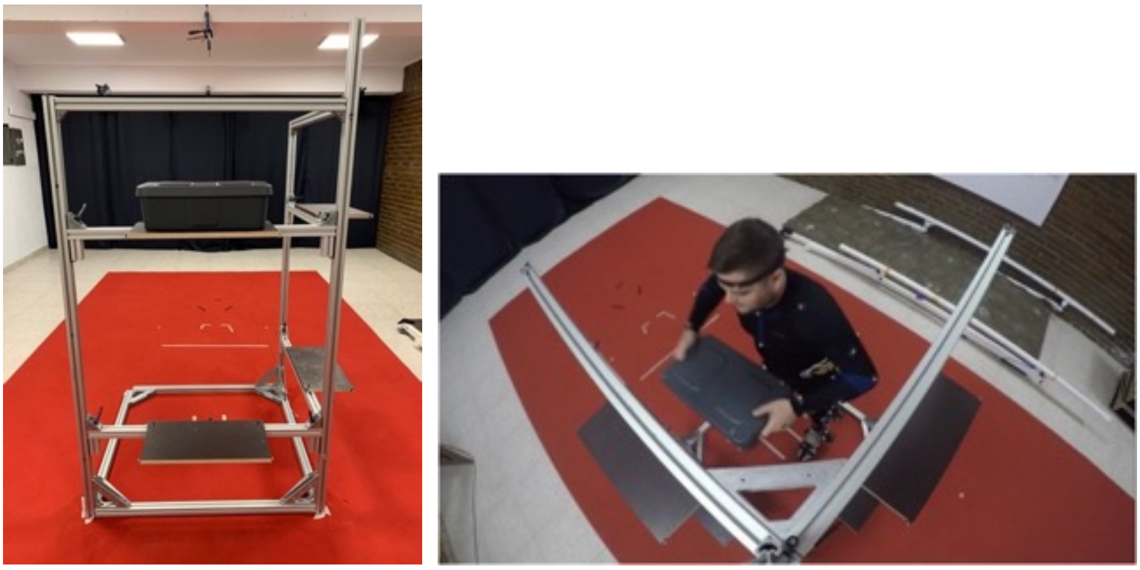


Figure 29: The '3D-grid' testbed for testing standing during manipulation skills.

3.2.3 Other systems purchased or already available

The facility will also have this equipment available ():

- An H3 exoskeleton to allow control algorithm tests, as an Open Robotic Platform: an implementation of ROS for these robotic platforms is foreseen, for the integration inside the facility. These robotic platforms are to allow third parties developing control algorithms to test them on these robots in the facility.
- EMG and EEG systems for physiological data gathering: these systems will allow to record physiological information synchronized with the systems in the facility, to provide to those teams that require biological information with properly captured data.
- Inertial measurement units, and photogrammetry Motion Capture Systems (MoCaps): these motion capture systems are being integrated in the facility with ROS2 in the frame of the MoCap4ROS project, funded by the cascade funding project ROSin. They will provide integrated and synchronized motion data to those teams requiring it.

These systems will be synchronized with the ROS environment in the facility in order to provide an overall synchronization of all internal and external equipment.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

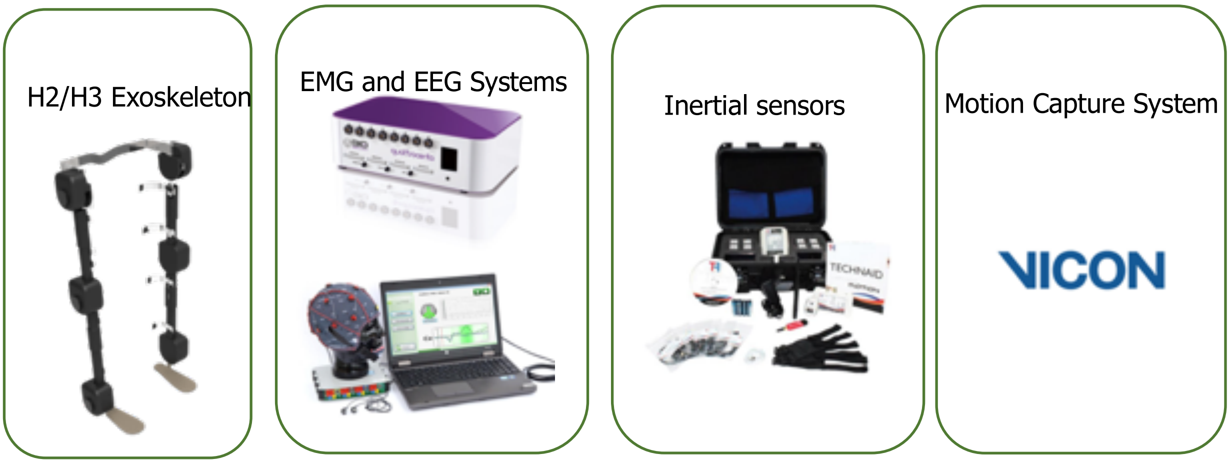


Figure 30: Additional equipment that will be available at the WR facility.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

4 Deviations from the workplan

There is currently a 1-month delay on the estimated release date, due to resources needed in the past two months for the resubmission of several deliverables as required by the first review.

5 Conclusion

This deliverable provides a complete overview of the two testing facilities, one for humanoids (located in Genova) and one for wearable robots (located in Brunete, near Madrid). In particular, it provides details on the definitions and organization of spaces, the technical requirements, the testbeds developed by both third parties and internally, and the additional equipment available at the facility (e.g. measurement systems or bipedal robotic platforms).

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 779963

25