Co-funded by the Horizon 2020
Framework Programme of the European Union

REACH

Deliverable D24: Partly functional / functional mock-ups and prototypes of PI²Us (associated with Task T5.4)

Abstract:
This deliverable report examines the outcome of the construction of functional or partly functional prototypes or mock-ups of Personalized Interior Intelligent Environment Units (PI²Us) for demonstration and testing purposes, associated with **Task T5.4**. The first part of this document will give an overview of the relation of this task to other tasks of **WP5**, other work packages, and the larger framework of the REACH project. The second part sets out the details of the progressive development from early concepts to the current prototyping stage. Moreover, the subsequent lab-based testing is described in the third part of the report. This includes both already carried out and planned testing activities for either early stage validation or final demonstration in a naturalistic test environment. Finally, part four summarizes the results and puts the different prototypes in perspective to the respective touchpoints and the overall REACH engine functionality.

Lead Partner:	TUM
Participants:	TUM, AM, Arjo, SK, HUG
Document Identifier:	REACH Deliverable D24
Version (Date):	1.0 (31.01.2019)
Due Date:	31. January 2019
Linked WPs/Tasks:	WP5/ T5.4
Type:	Public
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Date	Activity	Status
01.09.2017	Deliverable strategy ready	completed
01.10.2017	Prototyping and testing started	completed
01.09.2018	Deliverable structure ready	completed
15.12.2018	Major contents provided	completed
25.01.2019	Integration completed	completed
31.01.2019	Review completed, and report submitted to EC	completed

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 690425. The content of this report does not reflect the official opinion of the European Union. Responsibility for the information and views expressed in the report lies entirely with the authors.

Tasks of the involved partners with respect to the deliverable (and respective tasks) presented in this report:

Partner	Short task description
TUM	• Defining task scope • Leading the task • Coordination and communication between partners for individual contributions to this task • Writing and finalizing this deliverable report • Developing and building the smart furniture/PI^{2}U prototypes • Taking part in the trial execution at TUM-br2 laboratory • Preparing the laboratory for the testing activities • Developing and mounting sensing system into the test apartment • Supporting partners in proper data collection for the machine learning algorithms and for ethics commission application
AM	• Providing iStander device for the PI^{2}U-Stander development • Planning and detailing of PI^{2}U Stander and ActivLife
Arjo	• Providing Sara Combilizer for the PI^{2}U-Bed development • Consulting with regard to PI^{2}U-Bed development
SK	• Taking part in the trial execution at TUM-br2 laboratory • Consulting with regard to PI^{2}U-Bed development
HUG	• Advising and consulting the laboratory and future field tests

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Key expressions

Abbreviations for partners:

- **AH**: ArjoHuntleigh
- **AM**: Alreh Medical
- **CU**: University of Copenhagen
- **DTU**: Technical University of Denmark
- **EPFL**: École Polytechnique Fédérale de Lausanne, Switzerland
- **HUG:** Hôpitaux Universitaires Genève
- **SC:** SmartCardia
- **SK**: Schön Klinik
- **TU/e:** Eindhoven University of Technology
- **TUM:** Technical University of Munich
- **ZZ**: ZuidZorg

Activation: Physical and cognitive activation before an incident or way to keep patient as long as possible in a good baseline health state.

Activities of Daily Living (ADLs): Activity categories (e.g., dressing, bathing, feeding, etc.) which are necessary to maintain care independent living.

Ambient sensors: Sensors not worn on the body but integrated into the environment, everyday objects, PI²Us, etc., primarily supply in REACH the context and labelling.

Computer-aided design (CAD): The use of computer programs to aid in creating, modifying, analysing, or optimizing a design.

D: Deliverable report.

ELAN: A professional tool for the creation of complex annotations on video and audio resources.

Electrocardiography (ECG): The process of recording the electrical activity of the heart over a period of time using electrodes placed on the skin.

Electromyography (EMG): Electrical muscle function analysis.

End-user: Elderly citizen that are supposed to profit from reach services and products.

Engine: The “Engine” – in itself also modular with regard to its functionality – serves from the viewpoint of the end user as “invisible” back end system. In general, the end users (elderly) are supposed to interact with the “engine” primarily in an indirect way through the Touchpoints.

Graphical User Interface (GUI): A form of user interface that allows users to interact with electronic devices through graphical icons and visual indicators such as secondary notation, instead of text-based user interfaces, typed command labels or text navigation.

M: Project month within the project duration (e.g., **M19** refers to project month 19, namely August 2017)

Modularization: As defined, for example by (**Baldwin & Clark, 2000**), modularization can be considered as a means to control the internal complexity of a system e.g., by reducing and clarifying the interfaces between system elements.

Personalized Intelligent Interior Units (PI²Us): Smart furniture which is used to integrate the REACH concepts and functionality seamlessly into the different REACH use case settings. In a broader sense, Touchpoints will mainly materialize as "furniture" (i.e., elements that can be placed and moved within a particular environment) or setting (e.g., beds, bathroom furniture, mobile walkers/standers, large-scale interfaces, smart flooring tiles, smart tables, etc.). Additionally, the Touchpoints will also appear as ambient sensor add-on modules and wearables.

PI²U-MiniArc: Same concept as the PI²U-silverArc, however designed for private home use. Therefore, this PI²U is compact designed and mobile (details see in REACH **Deliverable T5.2/D22**).

PI²U-SilverArc: A PI²U, which serves as a main user interface, including an interactive table, as well as an ultra-wide screen project area, which is responding to gestures, and displaying rehabilitation games, recipes and health data (details see in REACH **Deliverable T5.2/D22**).

PI²U-Stander: The ActivLife from AM, interfaced to the REACH System as PI²U module (details see in REACH **Deliverable T5.2/D22**).

Physical Activity: Target condition of REACH. The systemized early detection and intervention-based prevention of physical inactivity and sedentary behavior in a variety of care settings such as homes and everyday life, day care centers, and other geriatric facilities will not only significantly reduce the risk of LTC admissions and re-admissions (and thus as targeted by REACH reduce overall healthcare cost) but also increase the elderly's functional performance, social participation, independence, and quality of life.

REACH Toolkit Wheel: A diagram that serves as a checklist of all major technologies across 11 various categories, which are integrated and implemented in the four Touchpoints and Engine within their respective use case settings.

Sensing: In REACH physical activity was further detailed as the target condition and categorized into Physical Activity Dimensions (PADs). Based on the PAD and the selected early detection regimes, a specific set of sensors, which is able to serve the selected condition, and detection regime, can be selected in a target-oriented manner.

Stakeholders: In REACH the term "stakeholders" refers to the entire network and the diversity of players, partners, shareholders, stakeholders, end users, organizations, companies, institutions, and others that relate to, act in, are impacted by, and/or are interested in the activities, developments, and goals of the project.

T: Task defined in the project proposal.

Thermal camera: A device that forms a heat zone image using infrared radiation, similar to a common camera that forms an image using visible light.

Touchpoints/Engine concept: The concept that structures the envisioned REACH product-service-system architecture into manageable research and development clusters.

Touchpoints: The "Touchpoints" will act as "graspable" front ends towards the end users (elderly). The Touchpoints will serve as data gathering devices and as mediators of services and interventions coordinated by the Engine towards the end user. Each Touchpoint is modular and made up of several subsystems which allow adapting the system both for a particular person or setting, as well as over time.

Use case setting: Use case setting refers to the four solution operators, and this report refers to them as use case settings, since they reflect concrete application scenarios.

Wearable sensor: Worn on the body, obtain in REACH primarily uni-/multivariate physiological signals.

WP: Work package defined in the project proposal.

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1 Background and summary of tasks and activities related to T5.4/D24

Task T5.4, and therefore the contents of this deliverable, are set within the larger context of the REACH (Responsive Engagement of the Elderly Promoting Activity and Customized Healthcare) research project. The demographic change taking place in Europe is expected to increasingly strain existing European healthcare systems. The aim of REACH is to create a product service system to transform care environments into personalized modular sensing, prevention, and intervention systems, which help to encourage senior citizens to improve their state of health.

To begin with, the key elements of REACH and the topics of **Task T5.4/Deliverable 24** in the context of WP5 and other tasks will be described in this chapter.

1.1 Deliverable and related tasks in the larger context of REACH and the Touchpoint and Engine concept

The “Touchpoint and Engine concept” (**Figure 1-1**) is the core of the system architecture of REACH. It is used to describe its high-level architecture and to define subsystems. The so-called product-service system architecture is structured through the “Touchpoint and Engine concept” into six manageable research and development clusters: four “Touchpoint” (TP) clusters, one Engine cluster, and one Interface cluster.

The Touchpoints represent the tangible connections between the users (seniors, informal/formal caregivers, physicians, etc.) and the REACH system. The Engine represents the cloud-based digital platform. The Interface comprises a set of specifications, allowing the Touchpoints and other products or services to connect to or interact with the Engine. A dedicated and independent development team from the consortium is assigned to each cluster (**Bock, 2017**).

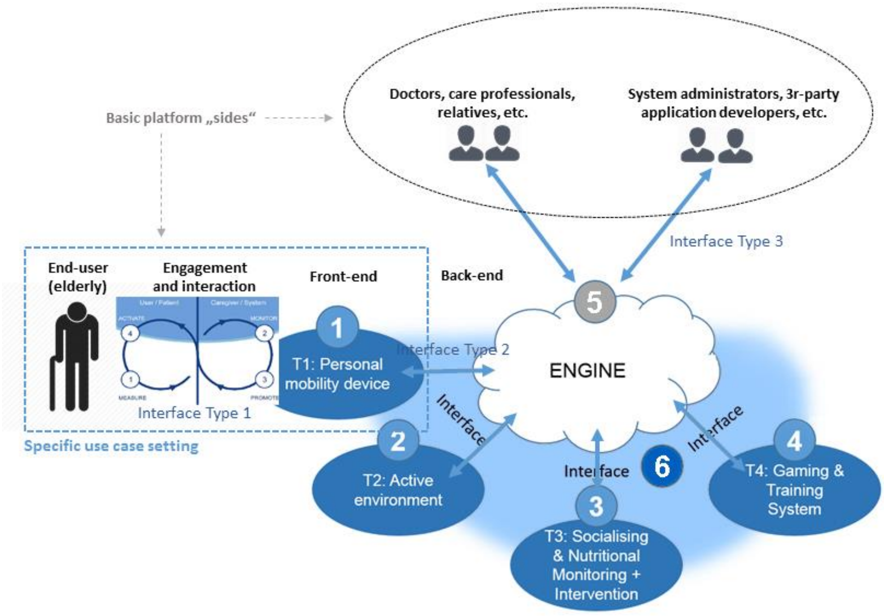


Figure 1-1 REACH Touchpoint and Engine concept

Furthermore, the so-called REACH Toolkit Wheel was introduced, in order to provide a better overview of the low-level implementation of REACH. It classifies the main technology into 11 categories, integrated and implemented in the four Touchpoints and the Engine, within their respective use-case setting (see **Figure 1-2**).

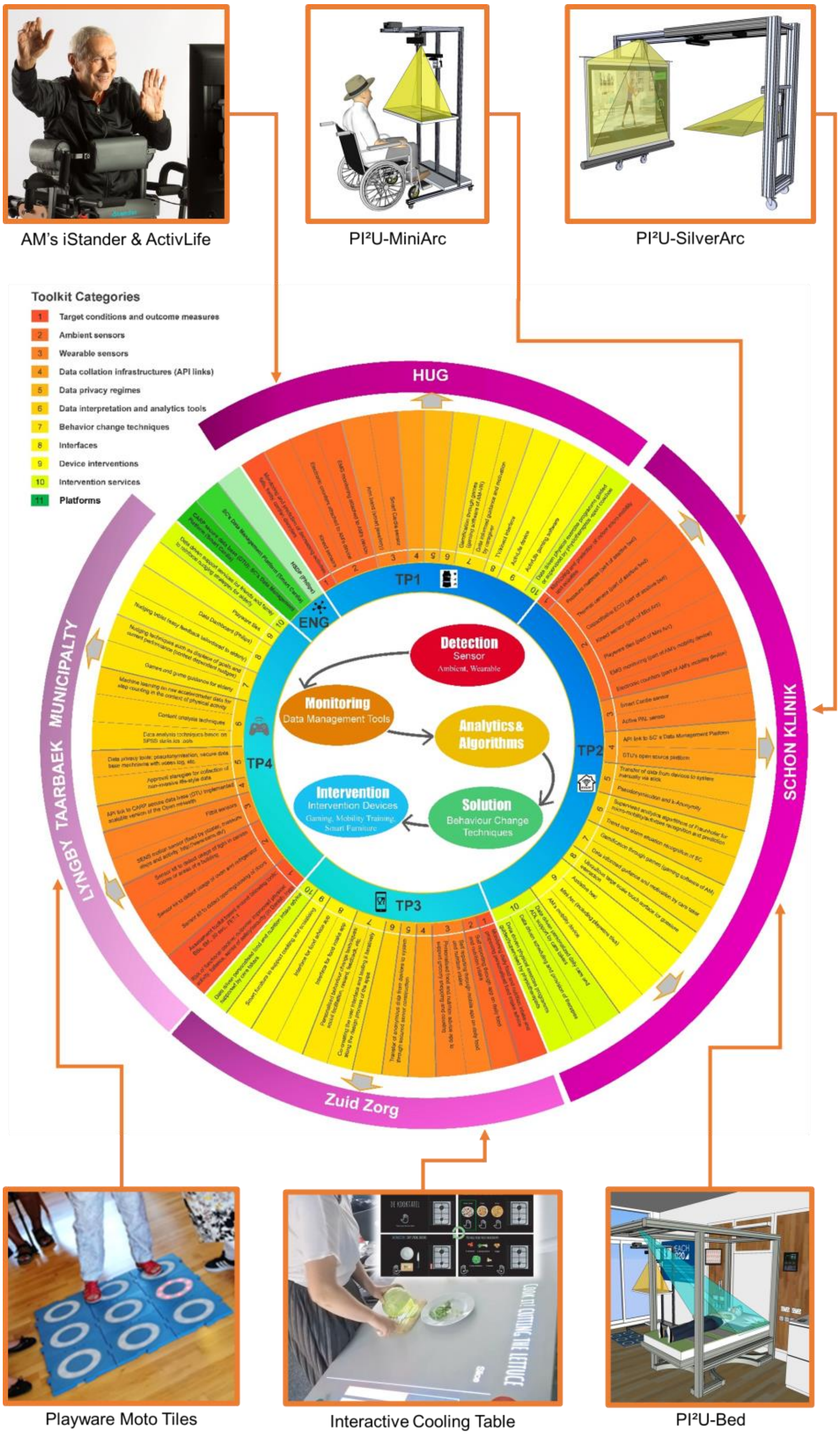


Figure 1-2 REACH Toolkit Wheel

1.2 Tasks/ Deliverables in the context of WP5

The work plan in REACH in structured into nine work packages (**WP**s). A work package is in turn subdivided into different, interdependent tasks and subtasks.

Work Package 5 (**WP5**) addresses research related to the Personalized Interior Intelligent Environment Units (PI^2Us), assistive smart furniture, which are used to integrate key REACH functionality, activities, and functional elements seamlessly into the different REACH health care environments. The way the tasks build on each other is explained in **Figure 1-3**. The first step was to identify and define the basic requirements and functions of the PI^2Us in **Task T5.1/D21**. After that, **Task T5.2/D22** dealt with the implementation of said requirements and functionality in the first designs and prototypes. Finally, **Task T5.4/D24**, subject of this document, addresses the process of the realization of the prototypes.

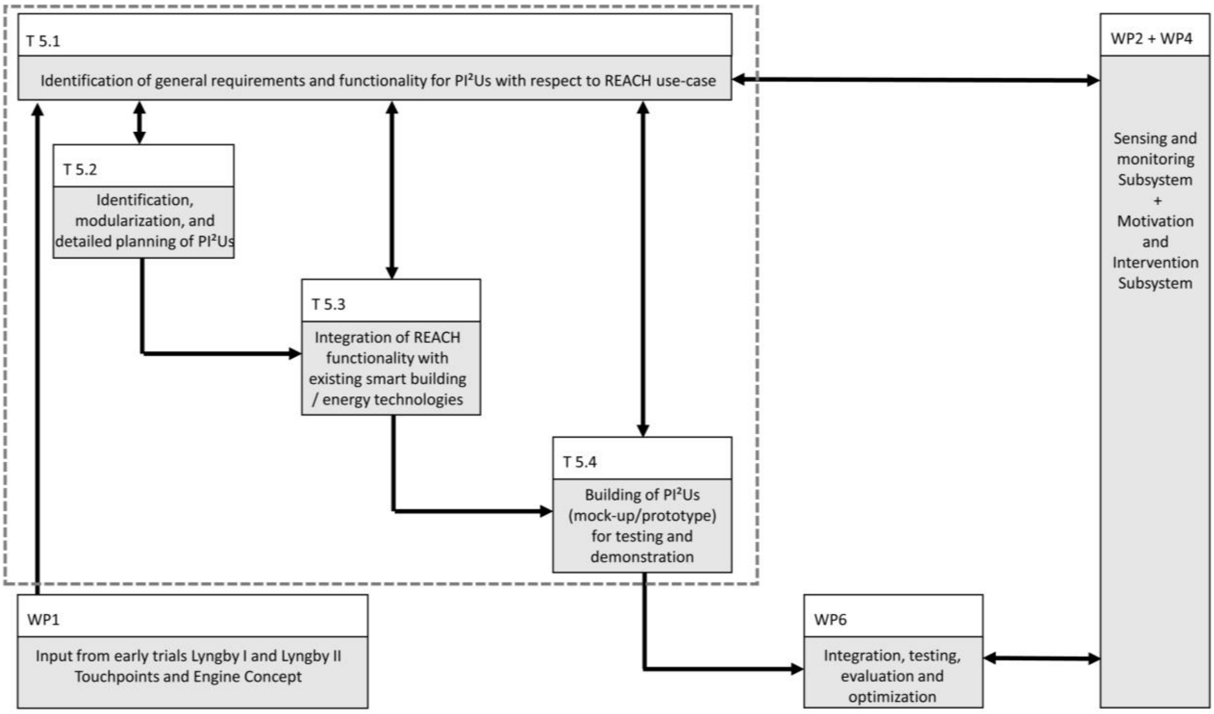


Figure 1-3 Structure of activities in WP5

In more specific terms, this means that the results of Deliverable **T5.1/D21** (i.e. the definition of requirements and basic functions and the identification of the relevant PI^2Us) are the basis for the subsequent development of each individual unit in the previous **Deliverable T5.2/D22**.

First of all, the design rationale and strategy for the PI^2Us needed to be specified. This includes the application of a design structure matrix (DSM), the use of modularization, and platform strategy in the design approach. The DSM serves as a tool to recognize the interdependency of different design parameters in the methodical development of the design of the (PI^2Us). The modular approach of the system architecture of REACH ensures adaptability and makes it possible to develop independent products that have the ability to interact with each other within the REACH plat-form environment. This means, the products can be developed to the specifications of each Touchpoint and can be tailored to the individual requirements of the end-users (i.e. the individual health needs of the senior citizens). An additional benefit is the more cost-effective, faster manufacturability, necessary to achieve mass customization.

Deliverable T5.2/D22 then presents the concrete, detailed designs for the PI²Us, namely PI²U-SilverArc, PI²U-MiniArc, PI²U-Bed, and PI²U-Stander in combination with ActivLife.

PI²U-SilverArc is developed to be used in large kitchens (e.g., a community kitchen, not least in order to encourage elderly to partake in communal activity). PI²U-MiniArc is the smaller variant of the PI²U-SilverArc. It is aimed at hospitalized persons or elderly living in smaller apartments. The PI²U-Bed is based on current hospital bed designs and is intended to assist patients and nursing staff in daily tasks such as eating, but also early mobilization of the patient. It can be also used in conjunction with PI²U-Stander and ActivLife. A docking mechanism facilitates the transfer of the patient to the PI²U-Stander, in order to use the rehabilitation device ActivLife for both motor and mental exercises.

After the realization of first prototypes, the PI²Us are to be tested in the test environment of TUM, which need be remodeled for this purpose. The according plans are also presented in **Deliverable T5.2/D22**.

The results of **Task T5.3**, the integration of REACH functionality with existing smart building/energy technologies, will be presented in the upcoming **Deliverable T5.3/D23**.

Task T5.4, the subject of this **Deliverable T5.4/D24**, concludes **WP5** with the concrete implementation of the designs in (partly) functional prototypes, in order to test and demonstrate them in naturalistic circumstances, to evaluate and optimize them, and in order to link them with other work packages, mainly **WP6** (see below). This will be explained in detail in the following sections of this document.

1.3 Relation to other tasks and deliverables

Outside of **WP5**, **Deliverable T5.4/D24** is related to a number of other tasks and work packages. The PI²Us were built partly on the equipment provided by Arjo and AM, and integrate elements developed in other WPs.

The PI²Us embody behavior change techniques (see **Deliverable D14**), help to mediate software functionality (see **Deliverable D20**), and were designed with accessibility and acceptability requirements (see **Deliverable D30**) in mind. Related outcomes and hypotheses of testing activities (including the past and upcoming ones) are addressed in **Deliverable D27**.

An important intersection between work packages is the development of ambient sensors in close cooperation with **WP2**, which have the purpose of monitoring the user in an unobtrusive way. Another example are the motivation and intervention elements, created in **WP4**.

Furthermore, **WP5** is the prerequisite for tasks in **WP6**. The latter aims to integrate, test, evaluate, and optimize the outcomes of the other WPs in order to achieve the desired objective: the integration of the subsystems into the REACH system. Therefore, the realization of the prototypes in **Task T5.4** is an important stepping stone.

1.4 Overview of contents presented in this Deliverable

In the following section, this deliverable will set out the development process from the concept stage to the prototype and provide an overview of the realized PI²Us, and the initial performance, usability, and feasibility test results. This includes PI²U-SilverArc, PI²U-MiniArc, PI²U-Bed, and PI²U-Stander. Therefore, **Chapter 2** will explain the design of the prototyping process, and the means by which the implementation was facilitated, including a description of the workshop and tools, as well as the laboratory testing environment and the field test and trial environments Schön Klink and Lyngby.

This is followed up by a presentation of the progress of testing (see **Chapter 3**). Information about the already completed testing in terms of functionality and laboratory testing will be provided, along with a description of the tasks that lie ahead.

Finally, a summary and conclusion, as well as an outline of the prototyping activity, regarding each TP and the PI²U's integration within the setting of the REACH Engine will be provided (see **Chapter 5**).

2 From concept to practice: built PI²U mock-ups and prototypes

The realization of the PI²Us (i.e. the mock-ups and prototypes that were implemented) required firstly the definition of the prototyping process, and secondly a number of tools and facilities, which are depicted in this section. Furthermore, the relevant PI²Us are reviewed, which were introduced in detail in **Deliverable T5.2/D22**.

2.1 Outline of the prototyping process

The whole prototyping process follows a development cycle which consists of 1) conceptual design, 2) building the prototype, 3) equipping the prototype with sensors and functions, 4) testing the functionality and performance, and 5) refining the design (see **Figure 2-1**). This process will ensure the quality and performance of the prototypes.

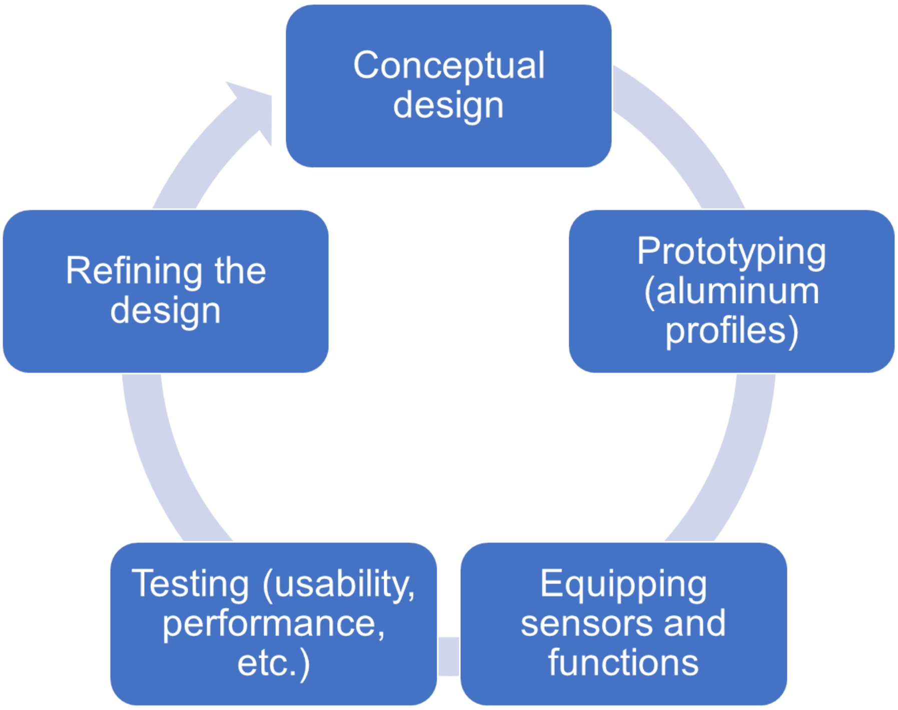


Figure 2-1 The development process of the PI²U prototypes

2.2 Tools and facilities utilized in the prototyping process

The tools and facilities which are used in the whole development process of the PI²U mock-ups and prototypes will be introduced in the following sections.

2.2.1 Mechatronics workshop and its tools

The Construction Robotics Laboratory at TUM (**Chair of Building Realization and Robotics, 2019**) provides a fully equipped mechatronics workshop and is supervised by a professional technician Mr. A. Bittner (see **Figure 2-2** to **Figure 2-5**). These tools include but are not limited to the circuit printer and the aluminum profile cutting machine. Also, a series of sensors and electronic devices are used to execute the functionality and laboratory testing.

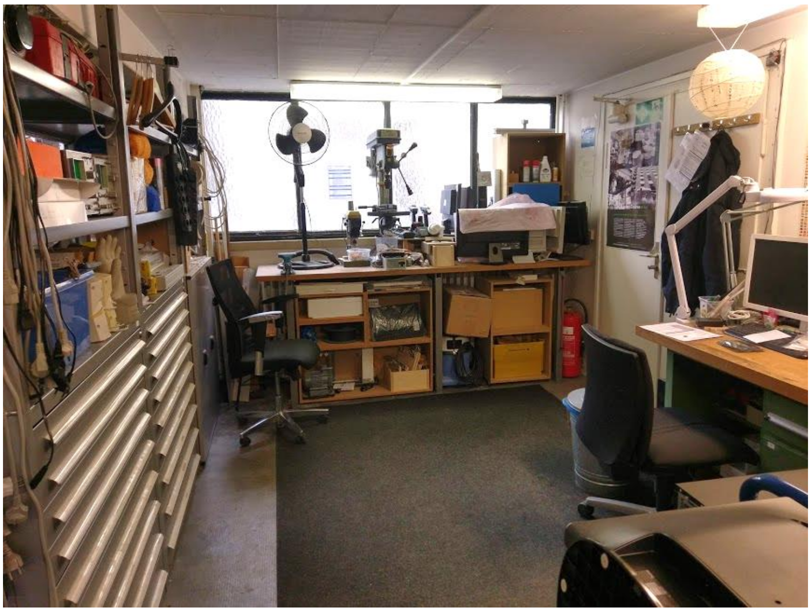


Figure 2-2 The mechatronics workshop in TUM's laboratory (part 1)

Figure 2-3 The mechatronics workshop in TUM's laboratory (part 2)

Figure 2-4 Circuit printer in TUM's laboratory

Figure 2-5 Machine to change aluminum profiles in TUM's laboratory

2.2.2 Functionality and laboratory testing tools

The following sensors and tools are integrated to execute the performance test (see **Figure 2-6**).

- SmartCardia Wearable Sensor (accelerometer)
- Pressure Mattress (placed on the bed surface)
- ActivPal sensors (accelerometer)
- Thermal camera (breath and body temperature detection)
- Microsoft Kinect (motion detection)
- MyoBand Sensors (EMG sensors and muscle movement detection)
- Step counter (integrated in the PI²U-Stander)
- Cameras (four fixed cameras and one mobile camera)
- Smartphones (accelerometer and Gyroscope — iPhone)
- MiniPCs (integrated in several PI²Us to enable user interaction), etc.

Figure 2-6 Overview of several sensors that are being used or under development in the functionality and laboratory tests

2.2.3 The flat as laboratory test setting in TUM's laboratory

In 2010, the Chair of Building Realization and Robotics established a 1:1 modular, 45m² large test flat that can be adapted within a few hours to different test scenarios. The test flat was built up due to a lack of facilities that allow the testing of new developments in the field of Ambient Assisted Living under controlled and comparable laboratory conditions. The flat was used to conduct usability studies with test persons in all ongoing research projects. Furthermore, the flat integrates the systems and subsystems developed in past and ongoing trials (for example intelligent chair, intelligent workspace, mechatronic wall, etc.) to a fully mechatronic and assistive environment (see **Figure 2-7** to **Figure 2-9**). According to the current plan, all the PI^{2}Us developed in Touchpoint 2 will be deployed and tested in this test flat from early March 2019.

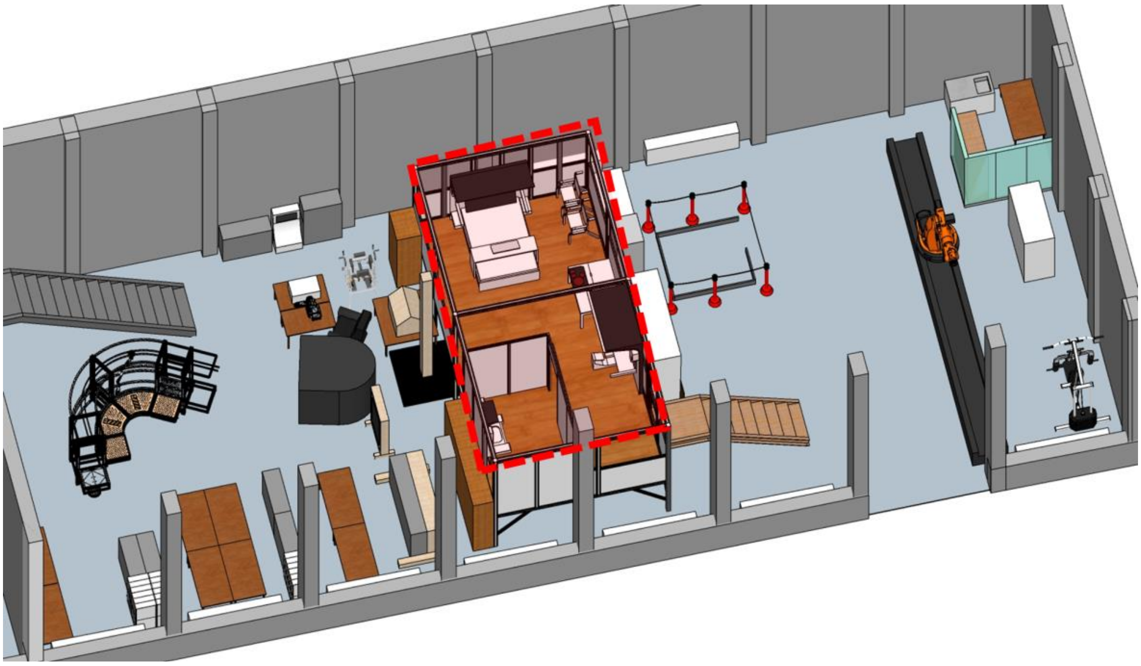


Figure 2-7 A simulation of the test flat in the laboratory of TUM

Figure 2-8 Perspective inside of the test flat

Figure 2-9 Testing activities in the test flat of TUM

2.2.4 Schön Klinik Bad Aibling as field test setting

As a key application partner in REACH, Schön Klinik is a family owned hospital group which currently has 8.800 employees in 17 German cities. The company focuses on psychosomatic medicine, orthopedics, neurology as well as surgery, and internal medicine. Since the early 1990s, it has grown to one of the five largest owner-managed clinic groups on the German market.

Schön Klinik Bad Aibling (founded 1994) is a hospital for neurological rehabilitation with 238 inpatient beds (including intermediate care), 29 intensive care beds, a unit for 10 rehabilitative day care patients, a stroke unit with 5 beds, a sleep laboratory and a neuropsychiatric treatment center for patients with dementia disorders (see **Figure 2-10**). The hospital covers all aspects of neurological rehabilitation with focus on the treatment of moderately to severely impaired patients (e.g., patients with cerebral ischemia or hemorrhage, traumatic brain injury, neurodegenerative diseases, hypoxia, inflammatory diseases of the central nervous system, Guillain-Barré-syndrome or critical illness neuropathy, spinal cord disorders). 800 people are currently employed at the Schön Klinik Bad Aibling. The various and outstanding therapeutic and nursing concepts are known throughout Germany and internationally.

Figure 2-10 Facilities in Schön Klinik Bad Aibling

The main objective of Schön Klinik Bad Aibling's physicians, nursing staff, and therapists is to restore the mobility, strength and endurance of our patients and therefore enable them to achieve their individual maximum independence. Our teams work with conventional therapies as well as innovative robot-assisted methods, following evidence-based treatment strategies. The concepts are individually compiled, based upon the patient's needs. The multidisciplinary team comprises of treating physicians, nursing staff, occupational, physical, neuropsychological, and speech/swallowing therapists. Information transfer is ensured by regular team meetings and software supported documentation. Motor rehabilitation is guided by 56 physical and 29 occupational therapists. The hospital has built up extensive experience for the use of several robot systems (e.g., various Armeo systems, MIT-Manus, Ekso Bionics, G-EO system, Lokomat, Spacecurl). These systems are used in the therapeutic setting as well as in clinical trials.

Schön Klinik Bad Aibling will make appropriate staff and equipment available to fulfil the duties described in the work packages. The team members are experienced in designing, implementing and conducting clinical trials according to GCP and MDD. The nursing staff involved consists of experienced professionals who will provide expert input about design and development to optimize the use cases and demonstrators. A high-performance hospital software system will support data generation to evaluate the effectiveness of the medical devices. Statistical evaluation will be performed by a research associate with many years of experience in the analysis of data from clinical trials (**Schön Klinik, 2019**).

After the laboratory testing at TUM, the PI²Us will be further transferred and tested with elderly test persons in clinical trials in Schön Klinik Bad Aibling from March 2019.

2.2.5 Lyngby as naturalistic demonstration/trial environment for elderly people who live at home

For the week of 13th-16th of May 2019, a major REACH interactive exhibition will be held at DTU, Copenhagen. In this interactive exhibition, the contents of each Touchpoint will be presented to the visitors through an interesting mix of posters and prototypes. The elderly citizens from local Lyngby area and care homes will be invited to test and comment on issues such as the usability of the REACH prototypes. This exhibition will be especially interesting for elderly citizens, caregivers, medical staff and physicians. In the meantime, there will be a symposium which invites guests, elderly citizens and experts from specific fields such as data analytics and behavior change.

This interactive exhibition will be an ideal naturalistic demonstration/trial environment of the REACH technologies for elderly people who live at home. Furthermore, REACH will benefit from an exceptional opportunity as EIP Group will hold its annual meeting at this REACH event. EIP AHA Action Group consists of approximately 100 organizations including care centers, industries, and public health authorities. It aims to understand the underlying factors of frailty so as to improve prevention strategies and manage frailty syndrome and its consequences in a more effective manner.

2.3 Systematic overview of the built PI^{2}Us

As previously described in detail in **Deliverable D22**, this section is a systematic retrospection of the built PI^{2}Us, which later will be tested in test settings at Technical University of Munich, Schön Klinik Bad Aibling, and Lyngby.

2.3.1 Patient apartment in 3D grids

As previously discussed in **Deliverable D22**, modularity provides many benefits and plays a major role in the design of prototypes in REACH ((**Ericsson & Erixon, 1999**), (**Baldwin & Clark, 1997**), (**Baldwin & Clark, 2000**)). Based on the current outcomes from four Touchpoints, TUM visualized a modularized patient apartment integrating all PI^{2}Us and key technologies in REACH to create a total interior living and care environment for elderly users.

The patient apartment is designed based on barrier-free design principles. The floor area is approximately 45 m^2 (about the same size as the test flat in TUM's laboratory). In these living spaces, the activLife rehabilitation devices in Touchpoint 1, smart furniture (e.g., PI^{2}U-SilverArc, PI^{2}U-MiniArc, PI^{2}U-Bed) in Touchpoint 2, socialized nutrition solutions in Touchpoint 3, and gaming/training devices in Touchpoint 4 (e.g., Playware Moto Tiles) are seamlessly integrated to create a comprehensive experience of the REACH platform for the users. In addition, all elderly users using this apartment are supposed to wear the SmartCardia wearable sensors.

The apartment follows modular design (described in detail in **Deliverable D22**), in which the sizes of all PI^{2}Us and furniture in the apartment are highly modularized (see **Figure 2-11** to **Figure 2-13**). Due to its high modularity, parts of the apartment can be easily adapted and rapidly deployed in different REACH use case settings in four European countries, which will then help the REACH consortium execute a series of testing activities. A GUI developed in REACH, interlinks the different REACH modules with each other, and enables the end user to control the REACH patient apartment at the same time.

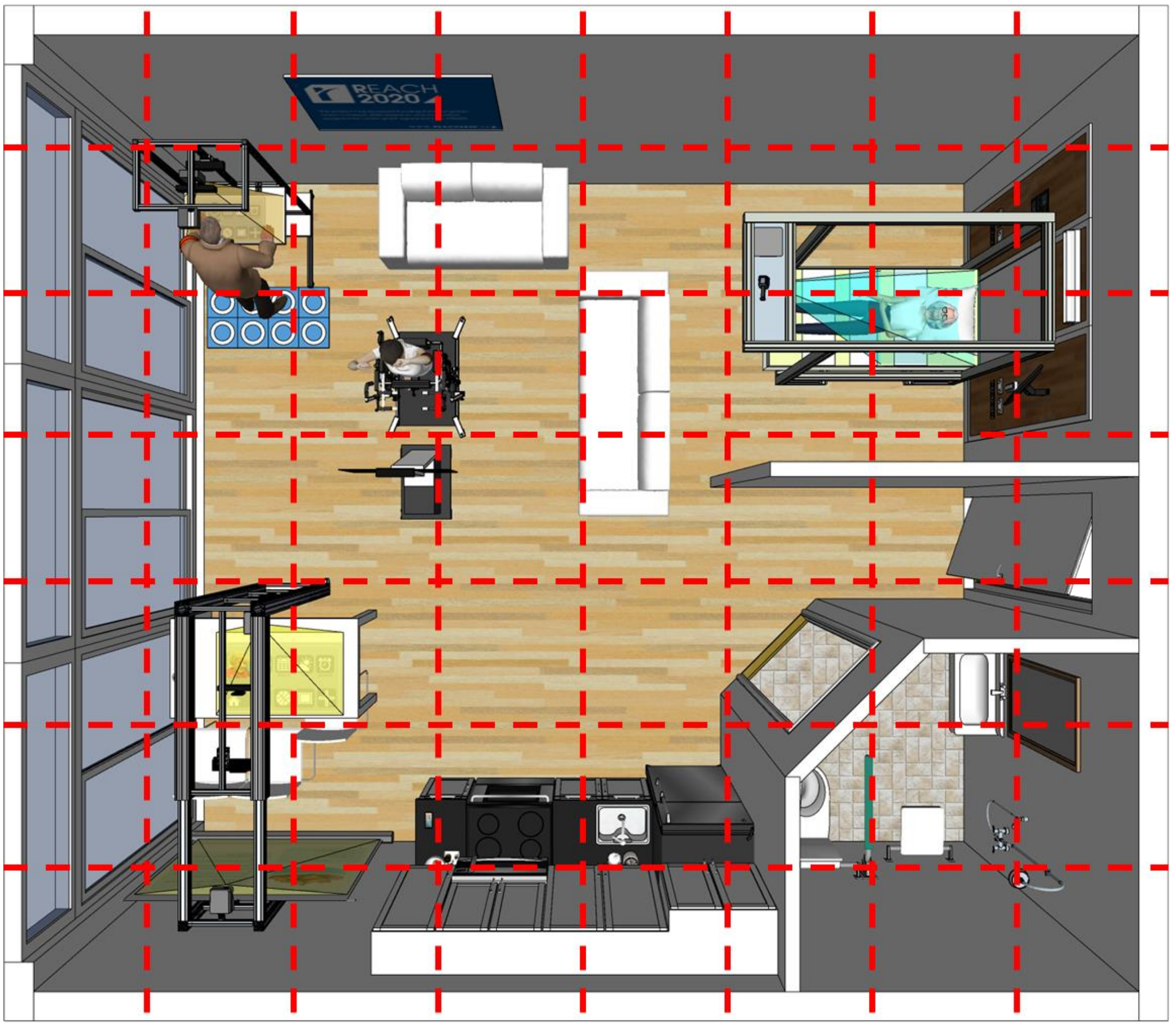


Figure 2-11 Simulation of the REACH patient apartment in 3D grids

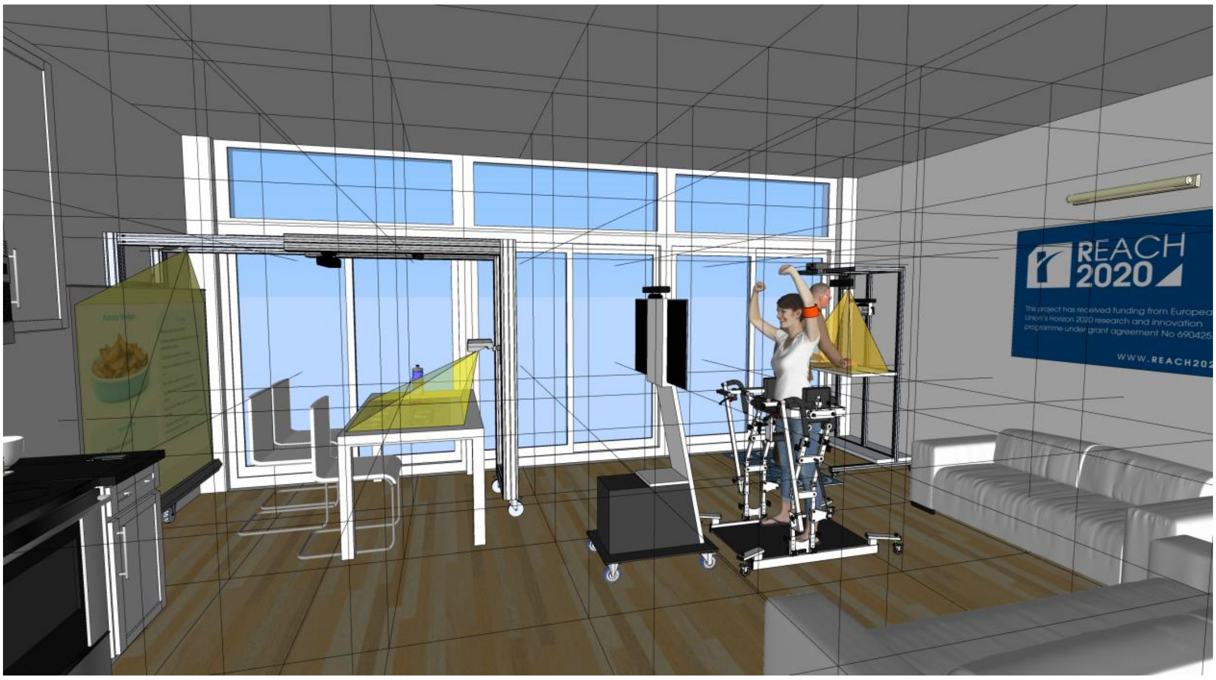


Figure 2-12 Perspective of the living space of the REACH patient apartment in 3D grids

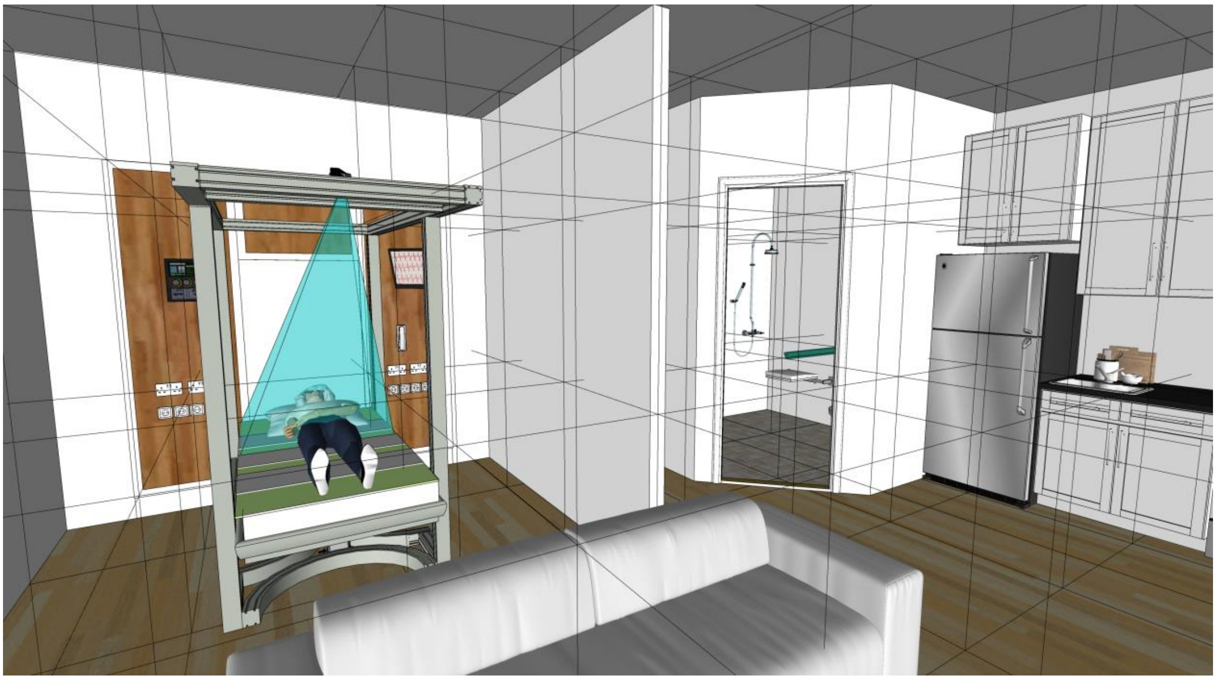


Figure 2-13 Perspective of the sleeping space of the REACH patient apartment in 3D grids

2.3.2 Overall description of each PI²U

As introduced in detail in Deliverable D22, the Personalized Intelligent Interior Unit (PI²U) is a special type of smart furniture that integrates the REACH concepts and functionality seamlessly into the different REACH use case settings. This section will review the PI²Us developed by the project team in Touchpoint 2. The relevant PI²Us including PI²U-SilverArc, PI²U-MiniArc, PI²U-Bed, and PI²U-Stander are briefly described as follows:

<u>(1) PI²U-SilverArc</u>

The PI²U-SilverArc was developed for use in a large kitchen or dining space (e.g., a community kitchen). It offers an interactive projection area in the kitchen, where recipes and games can be displayed. It also has a foldaway projection area where a training program can be displayed (see **Figure 2-14**). The round shapes, wood material, and bright colors give the PI²U-SilverArc a warm and inviting appearance.

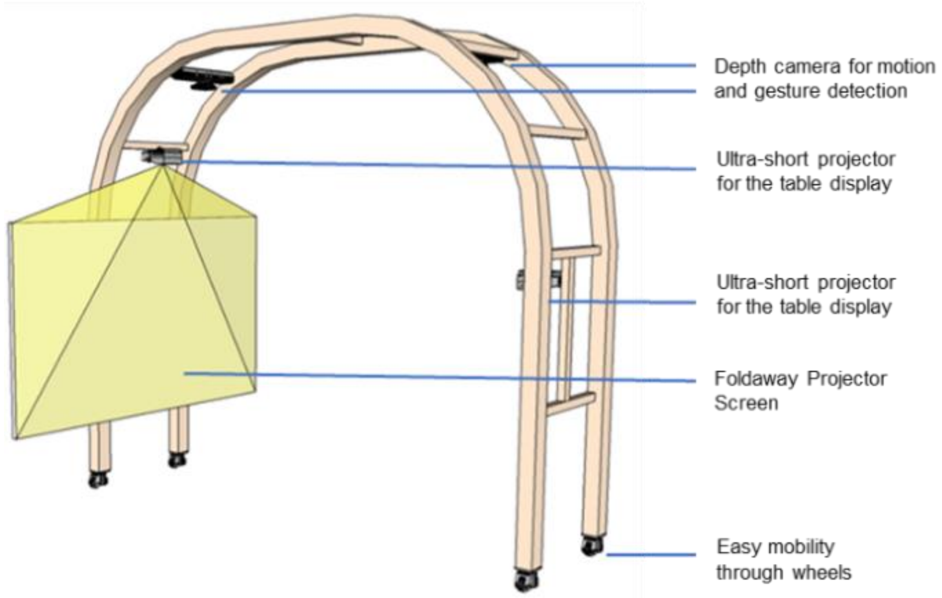


Figure 2-14 Preliminary design of the PI²U-SilverArc

The design of the PI²U-SilverArc cannot be directly converted into a prototype. For example, the material of the prototype and the final product differ substantially. After evaluation, it was decided that MayTec's modular aluminum profile system is suitable for building the prototypes (**MayTec, n.d.**). MayTec offers a wide range of modular profiles, accessories, and different connection possibilities. Simple changes can readily be made after the first test by using the MayTec system. Furthermore, on grounds of cost savings, the curves were omitted in the prototypes because they mainly serve an aesthetic function and are not necessary for the testing.

Figure 2-15 shows in detail how the technical equipment is integrated into the prototype. An ultra-short projector is fixed above the projection screen. It was purposely decided against a mounting under the projection surface, since the dust load for the projection lens would increase. Depth cameras are attached to a sliding system so that their positioning can be adjusted.

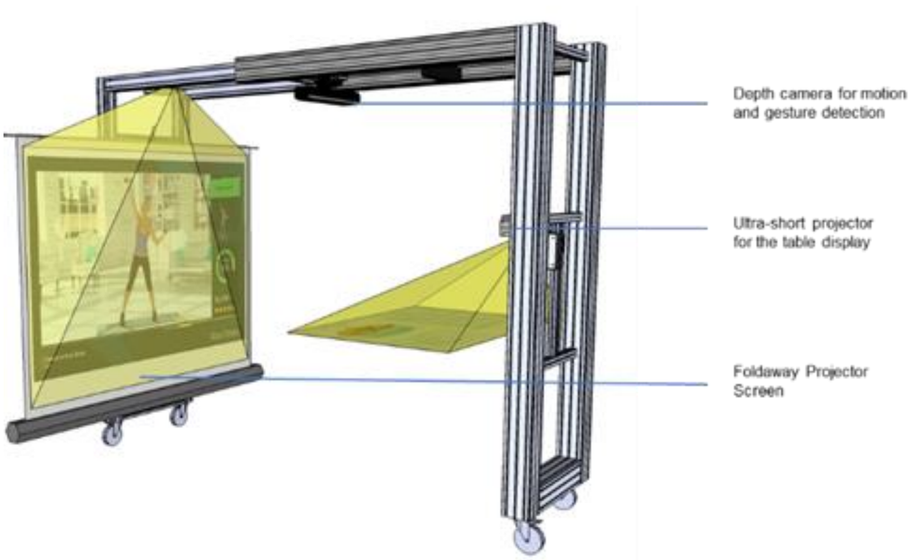


Figure 2-15 Prototypical version of the PI²U-SilverArc

(2) PI²U-MiniArc

The PI²U-MiniArc can be considered as a flexible and smaller variant of the PI²U-SilverArc, which is designed to assist in the training and moving of the elderly who are in hospital or live in smaller apartments. An ultrashort projector can project the user interface on its foldaway table or on a separate table as needed. In addition, a motion-sensing camera (Microsoft Kinect) is integrated to detect the user's gestures, enabling the interactive gaming function. There is another projector on top of the device that can project extra information onto a wall. This prototype is equipped with wheels and thus is mobile. **Figure 2-16** and **Figure 2-17** respectively demonstrate the preliminary design and the final prototypical version of the PI²U-MiniArc.

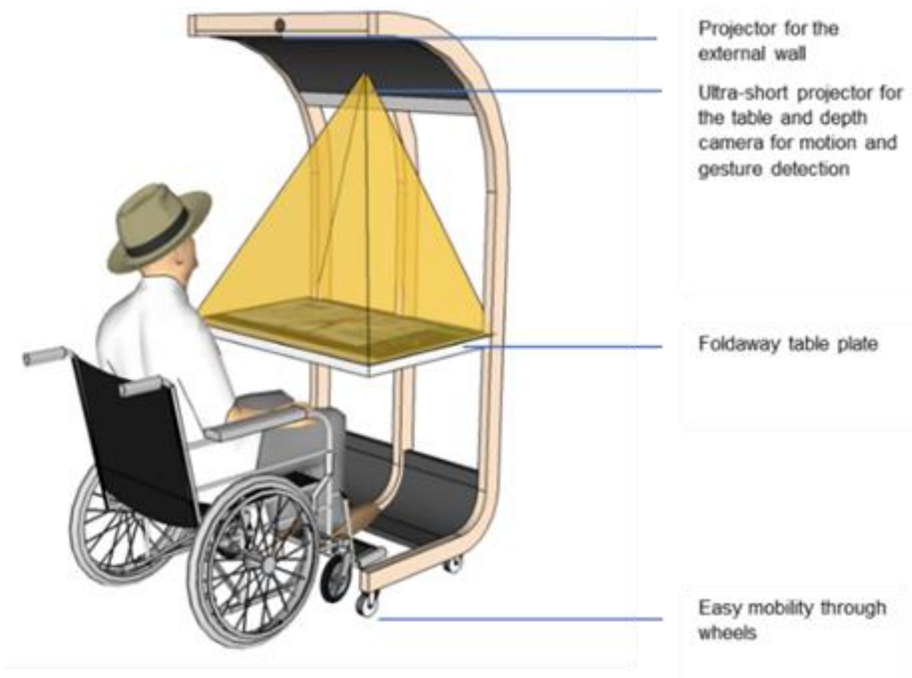


Figure 2-16 Preliminary design of the PI²U-MiniArc

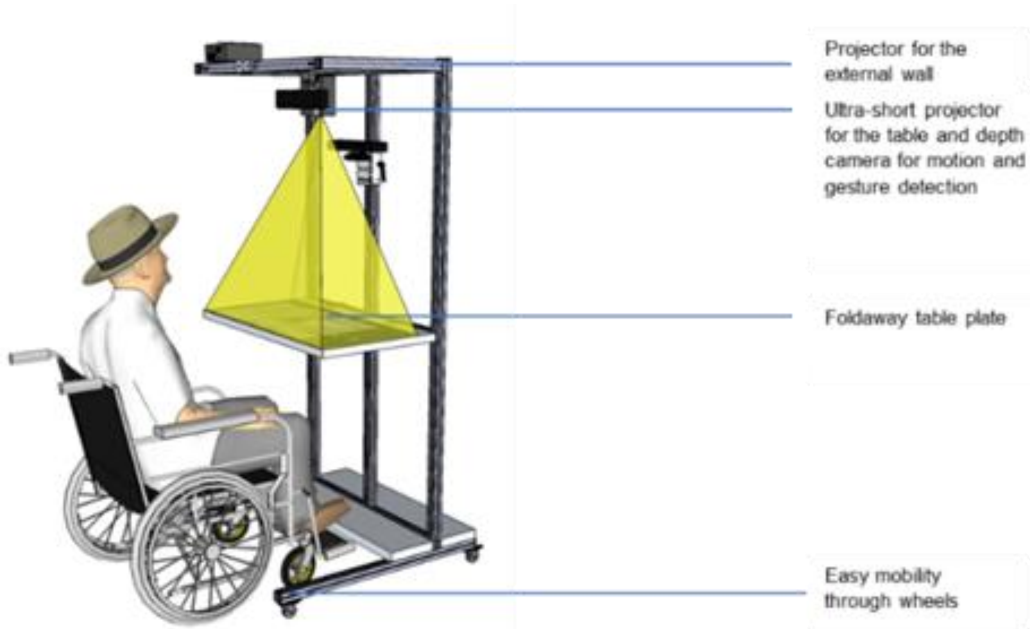


Figure 2-17 Prototypical version of the PI²U-MiniArc

(3) PI²U-Bed

As shown in **Figure 2-18**, the first design of the PI²U-Bed resembles a normal bed for private use. A special feature is an arc-shaped frame that covers the entire length of the bed, which allows for an easy integration of sensors and technologies such as a thermal camera for breath detection and a projector for the bed. The height of the bed can be adjusted. On the one hand, this feature makes it possible for the caregivers to work at a height that is comfortable for their torsos. On the other hand, the lowest height of the bed facilitates the transfer of the patient from the bed to other functional units such as a wheelchair. The bed can be set to both a sitting and a vertical position. The sitting position allows the bed to support the patient and the nurse in many tasks such as eating, while the vertical position is especially apt for patients in an Intensive Care Unit (ICU) who must perform the transfer from lying to vertical position. The passive standing that is enabled by a standing frame aims to improve respiratory function and cardiovascular fitness, increase the levels of consciousness, functional independence, and psychological well-being, and reduce the risk for delirium and the adverse effects of immobility (**Stiller & Phillips, 2003**).

In order to adapt the bed system to each patient’s needs, a modular docking system has been added to the design. Modules providing additional functions such as a toilet, physical training, transfer, and mobility can dock at different positions in the frame of the bed and are symmetric and self-guided. For example, with the Leg-curl Training Module (see **Figure 2-18**), the patient can rest on their stomach and use their legs to move the weight up and down. Training muscles is important to perform daily tasks.

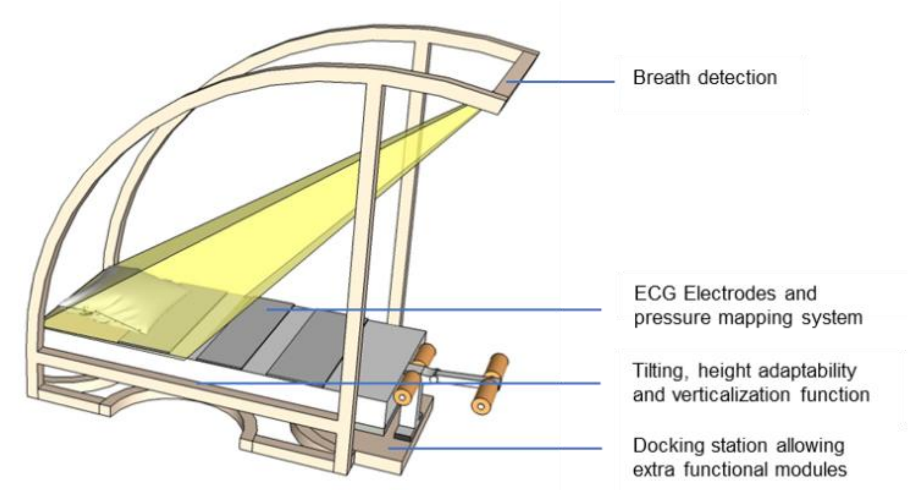


Figure 2-18 Preliminary design of the PI²U-Bed

To examine the concept of the PI²U-Bed, a prototype was planned and built. **Figure 2-19** shows the final design of the PI²U-Bed prototype that was manufactured.

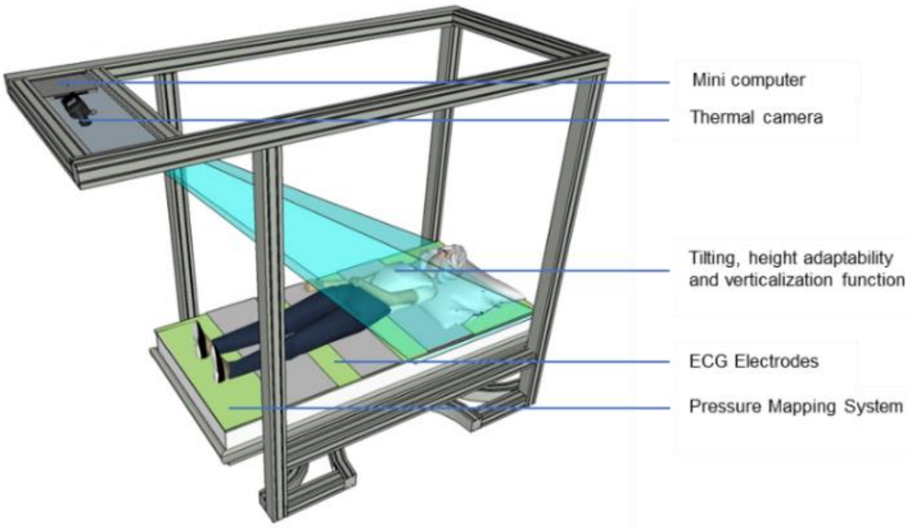


Figure 2-19 Prototypical version of the PI²U-Bed

In the **next step of prototyping the PI²U-Bed** (from early February to April 2019), the project team will adopt a rehabilitation device developed by Arjo called Sara Combilizer (**Figure 2-20**) as a key functional component of the PI²U-Bed.

Figure 2-20: Sara Combilzer by Arjo

The Sara Combilizer is a combined tilt table and stretcher chair, which allows passive transfer of patients out of bed (**Arjo Huntleigh, n.d.**). The general idea of this project is the expansion of Sara Combilizer from a temporary reactivation device to a rehabilitation tool which can be used over the course of days or weeks in a continuous way. It ought to accompany mainly elderly people on their way of rehabilitating back into a relatively independent lifestyle (**McWilliams, Atkins, Hodson, & Snelson, 2017**). Currently, the functionality of the Sara Combilizer (e.g., sitting, verticalization, mobility, etc.) was successfully tested in TUM's laboratory (see **Figure 2-21**).

Figure 2-21: Functionality test of the Sara Combilizer in TUM's laboratory

The project involves both expanding the functions of Sara Combilizer, including motorized driving and steering, as well as a bedframe to which it docks, and which serves the patient with a variety of features.

The target group is elderly people who have suffered rapid health decline in one form or another, for example stroke and from which there is a realistic prospect of rehabilitating sufficiently back into an independent lifestyle. They are to spend day and night on the Combilizer bed which serves them with a variety of recovery functions such as fitness devices and safe docking function for the mobilizer. In the meantime, entertainment functions are to be provided in order to also allow them to stay mentally active over the course of their rehabilitation.

The bed's structure is to be formed by a frame of aluminum or timber profiles (see **Figure 2-22** on the next page). It is to house an array of features:

- Fitness devices: Several fitness devices have been conceptualized to be included in the system.
    - Rowing machine: this can either be implemented by handles on the side which the patient rotates in a rowing-boat like way, or a rope coming from the front which the patient pulls towards them while being fixed to the Sara Combilizer with the seatbelts.
    - Cycling: a cycling device can be let down at the bed's end along rails on the verticals with which the patient can strengthen their legs.
    - Leg-Pushing: similar to the cycling device, a leg-pushing device can drive down at the bed's end with the patient having to push it away with their legs.
    - Pull-down: a rope including a handle is let down from the top. The patient must pull the handle down with their arms while a resistor on the other end of the rope acts as a counterweight.
    - Push-away: while the patient is in the sitting position, a horizontal bar can be assembled in front of the patient's upper body which they have to push away with their arms.

- Entertainment functions: The bed is to contain functions for visual and acoustic output, which can both be provided by a television screen. Apart from serving for entertainment purposes, mental training programs can be included. Moreover, the visual output can be combined with the fitness devices, allowing for a more tangible experience. For example, a rowing or cycling game can be implemented in which the patient is visualized to move through a landscape at a speed according to their fitness input. The goal is to both motivate the patient to exercise as well as to provide them with a way to escape their monotonous physical surrounding.

- Mobilizer docking: The Mobilizer can be docked at the frontside of the bed manually by care personnel. This facilitates an easy and safe shift from the Sara Combilizer to the mobilizer and back, eliminating any concerns of one of the two devices moving away unexpectedly which would potentially result in an injury of the patient.

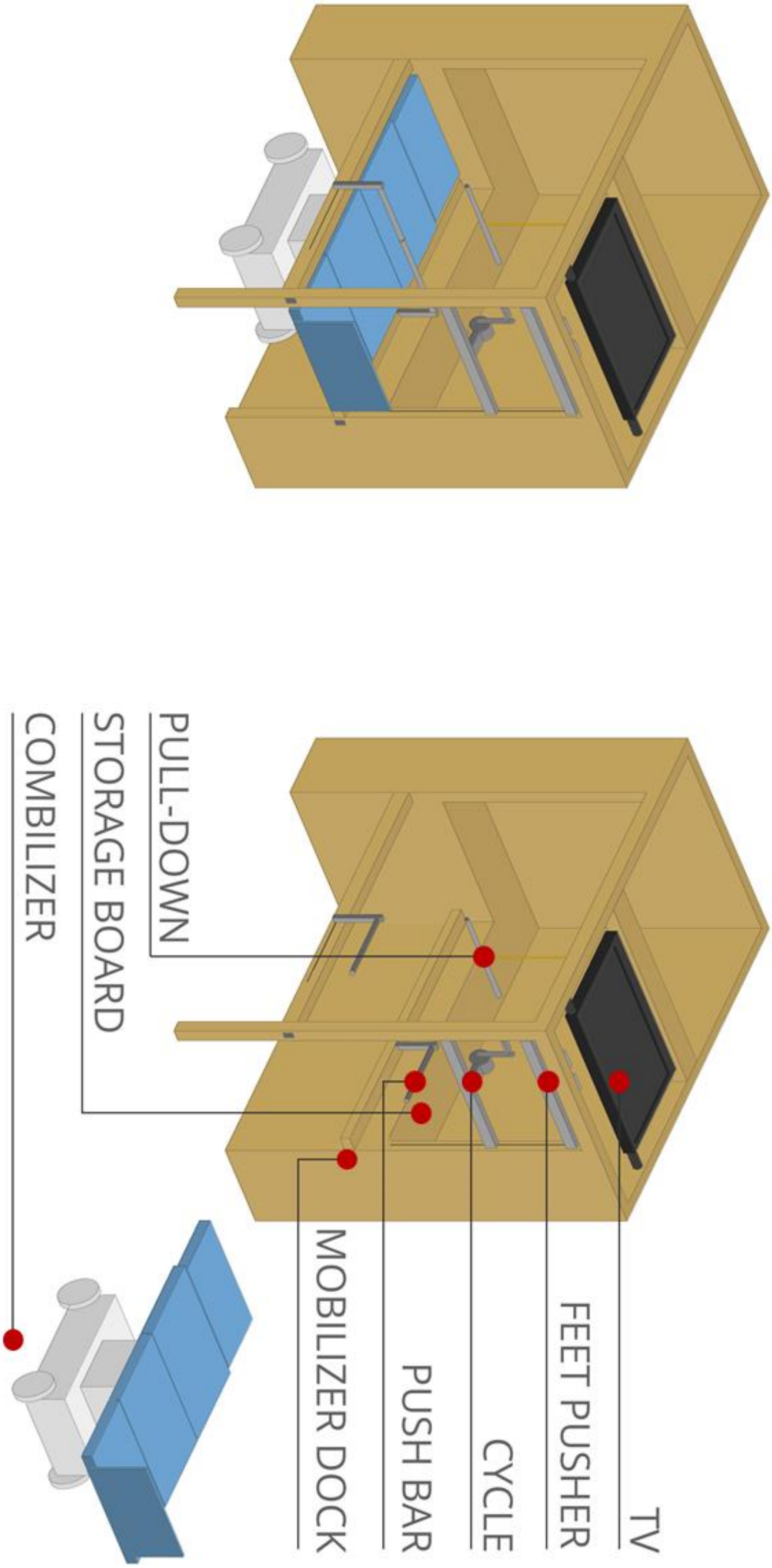


Figure 2-22: The conceptual sketch of the next prototype of PI²U-Bed using the Sara Combilizer

The Sara Combilizer is to be expanded to contain motorized drive and steering which can be operated by the patient, allowing them to change their surrounding independently without aid by care personnel. The speed is to be limited to 5km/h to ensure safety (**Figure 2-23**). A joystick could be integrated to control the mobilized Sara Combilizer.

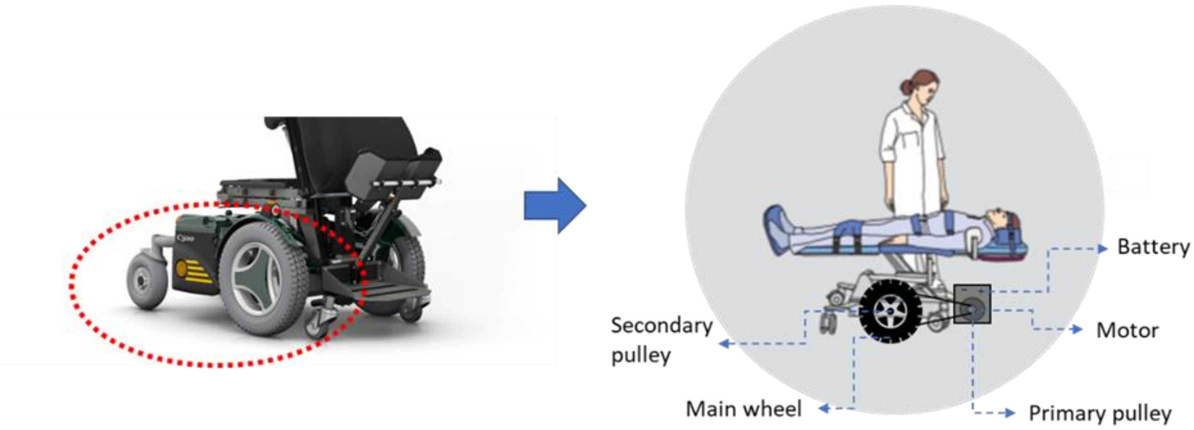


Figure 2-23: Proposal of the added electronic mobility component to the Sara Combilizer

One particular challenge is docking the Sara Combilizer to the bed. Navigating it into the correct spot manually in a motorized way is considerably difficult. If the Sara Combilizer is to work without the aid of care personnel, sensors must be included which allow the Sara Combilizer to drive in and out of the bedframe automatically. This eliminates the need for mechanical docking since the electronic brakes of the Sara Combilizer can ensure stability while the autonomous mode makes sure it is positioned in a correct way. Only small-scale wheels are to be implemented in order to ensure smooth and gapless docking. Ideally, inductive charging is included so that batteries do not have to be switched but can charge while the Sara Combilizer is in its default position.

<u>(4) PI²U-Stander</u>

The PI²U-Stander is designed to activate the physical and mental activity of people of old age whose daily activity level has decreased. It is used to prevent elderly people from falling and provides effective support for cognitive processes through the combination of physical and cognitive exercises. The device is equipped with a mechanism to assist the elderly user to stand up and to perform movement exercises of the ankles, knees, and hip joints. A special corset and a seat ensure safety during the exercises that strengthen the back and abdominal muscles by lifting the legs. It also allows the user to maintain a safe, upright standing position and perform balance exercises as well as exercises where the upper body parts are activated using the ActivLife gaming platform (**Kozak, et al., 2017**). Due to its flexibility and reasonable size, the system can be easily deployed in spaces such as living rooms and bedrooms (see **Figure 2-25**).

Figure 2-24 PI^2U-Stander (Image: Alreh Medical)

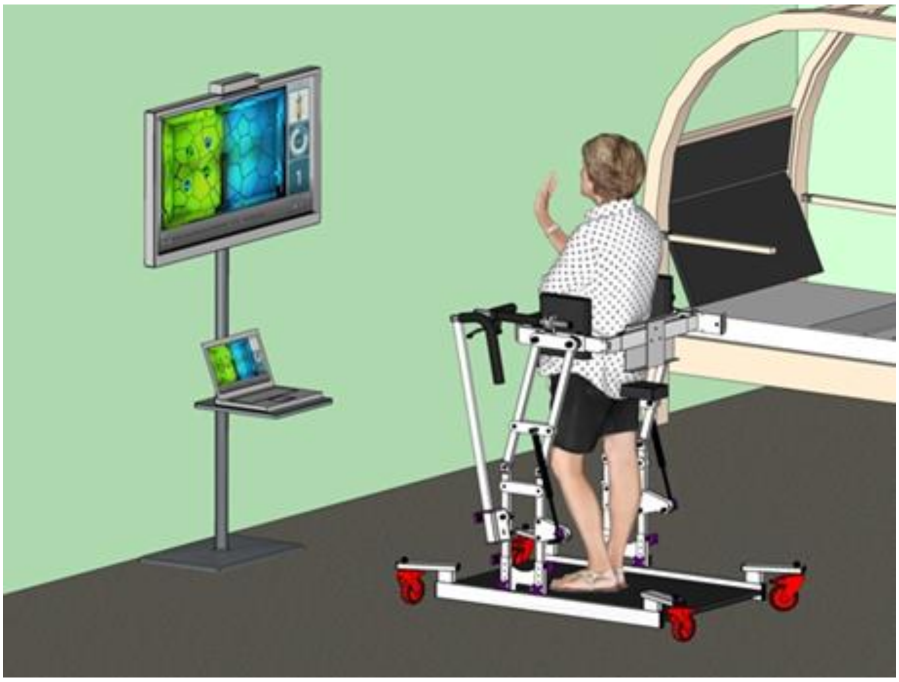


Figure 2-25 ActivLife system deployed in a bedroom environment

3 Laboratory-based functionality and methodology testing

As outlined in **Subsection 2.1**, the prototyping process includes a number of testing measures. The execution and results of the already completed tests (e.g., functionality, laboratory, performance tests) as well as the upcoming activities are described.

3.1 Completed functionality testing

As mentioned in the previous section, the project team in Touchpoint 2 developed a series of Personalized Intelligent Interior Units (PI²Us), which are a special type of smart furniture that materialize the REACH concepts and functionality seamlessly into the different REACH use case settings. The PI²Us consist of the PI²U-SilverArc, PI²U-MiniArc, PI²U-Bed, and PI²U-Stander. The PI²U prototypes are manufactured, currently deployed, and tested for major sensing, monitoring, and analysis activities in REACH in the laboratory of Technical University of Munich (TUM) (see **Figure 3-1**).

Figure 3-1 The prototypes of PI²Us (e.g., PI²U-Stander, PI²U-Bed, PI²U-SilverArc, PI²U-MiniArc) deployed and tested in TUM's laboratory

The electrocardiogram (ECG) sensors, which are embedded in the PI²U-Bed, will provide the medical staff with sufficient data regarding the patient's heart activity during the sleeping period. Additionally, this aspect can support the early detection aspect of the REACH project. **Figure 3-2** presents the sensor integration on the PI²U-Bed, which resulted in the ECG measurement signals in the second image (**Figure 3-2** middle). In order to implement such sensors, flexible plastic material was used to improve patient comfort and measurement (**Figure 3-2** right). The ECG implementation uses two electrodes to produce the ECG signal.

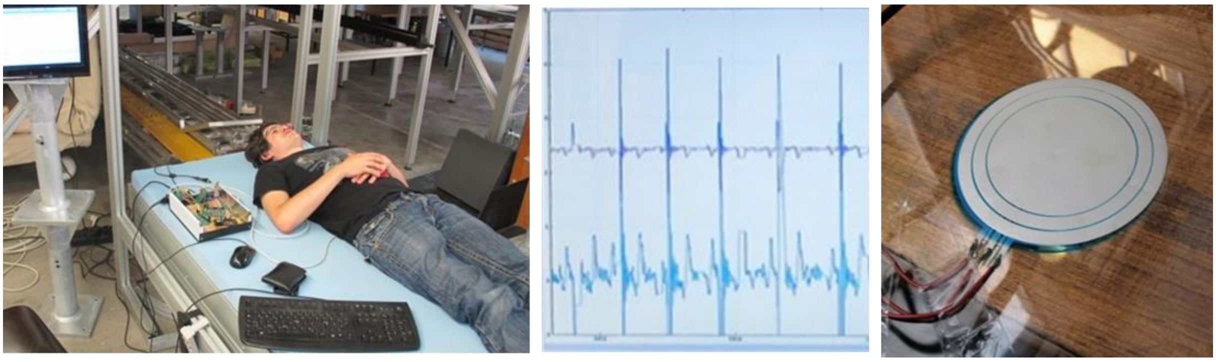


Figure 3-2 Testing of the ECG sensors on the PI²U-Bed

An important issue when considering an immobile patient's care is the prevention and management of pressure sores or decubitus. In order to implement the early detection and prevention aspects of REACH in the PI²U-Bed, it was decided to implement and integrate a pressure-sensing mattress. This mattress monitors the peak pressure points of a person lying on the bed. Using this data, the REACH Engine can monitor peak pressure points and inform the care personnel for repositioning the patient before they develop decubitus (see **Figure 3-3**). This sensor provides other functions as well. Using this sensor, a breath frequency monitor (for patients sleeping on their stomach) as well as a micro-mobility monitor are currently under implementation. Additionally, the project team is currently investigating the possibility of monitoring heart rate.

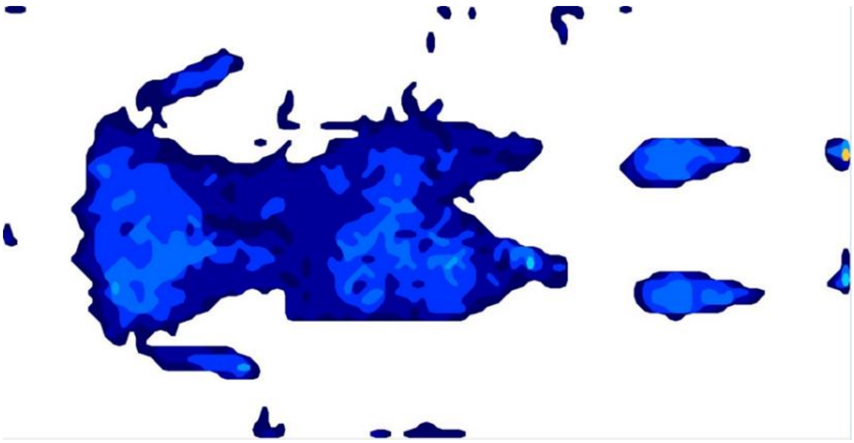


Figure 3-3 Body peak pressure mapping (Image from Tekscan)

The thermal camera targets two major objectives: 1) breath frequency monitoring over the nostrils during sleep on the back, and 2) body temperature detection/monitoring over the eyes (see **Figure 3-4** and **Figure 3-5**). In the first implementation of these modules in TUM's laboratory, the results showed the following: breath frequency monitoring is possible and implemented via the nostrils and that the body temperature monitoring is implemented (monitoring the body temperature via the eyes is, naturally, only possible before the patient goes to sleep). There is a small limitation regarding the implemented prototype; due to the resolution of the current thermal camera, it is only possible to monitor these factors in a range of approximately 50 cm distance from the patient's face. As a result, the thermal camera must either be mounted at the appropriate distance to the face, or the thermal camera must be replaced with a higher quality camera.

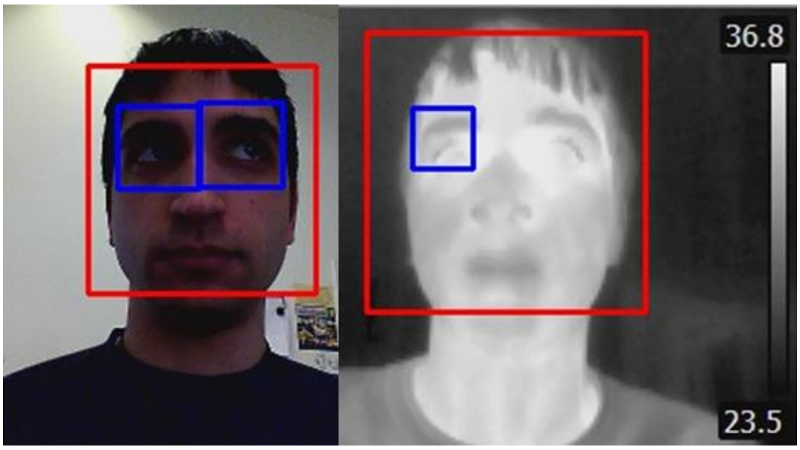


Figure 3-4 Eye following and body temperature measurement

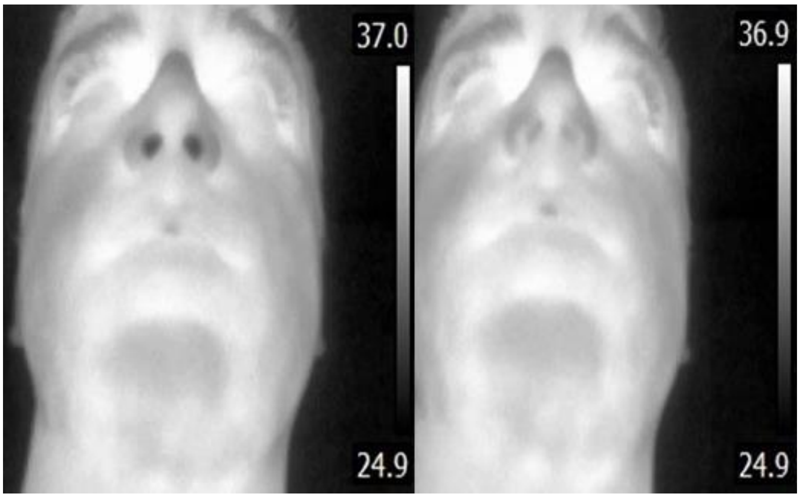


Figure 3-5 Respiration rate monitoring and body temperature measurement

The Kinect sensors, integrated into the PI²U-MiniArc and PI²U-SilverArc, are used for gesture recognition by considering the hand motions from the user side (see **Figure 3-6**). The Kinect was programmed by using the standard libraries from Microsoft. Therefore, it is necessary to continue with Microsoft Windows as the operating system since the libraries of the Kinect are not compatible with other operating systems. The control program of the Kinect gesture recognition was programmed using visual studio and was developed separately from the Graphical User Interface (GUI). Furthermore, the software development of the mounted Kinect on the PI²U-MiniArc is finalized including the adjustability for recognizing gesture at two different distances (standing table surface and sitting table surface).

Figure 3-6 User interface and Kinect sensor in PI^{2}U-MiniArc

Designed and implemented as “battery-based” and “plug-and-play”, the stand-up counting sensor is mounted on the Alreh Medical device in a specific way, so that the clinical certificate of the device will not be undermined (see **Figure 3-7**). This sensor counts the number of "stand-up" events and transfers this count to a local server via WiFi. Additionally, this sensor is implemented with consideration of very low power consumption. With the implemented battery, it will run for more than three months without the need for recharging the battery.

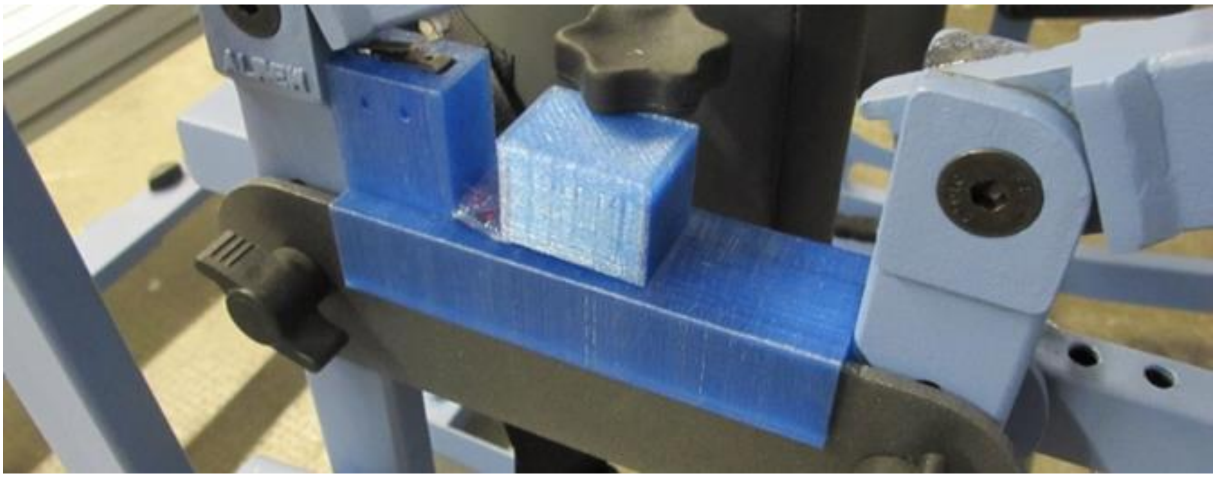


Figure 3-7 Stand-up Counter embedded in the PI^{2}U-Stander

It is planned to implement an activity sensing system for the Alreh Medical device (see **Figure 3-8**). This activity sensing system will be fused with the current gaming interface of the Alreh Medical device in order to enable lower body interactions with the games. In the first trial, the electromyography (EMG) sensing was implemented and tested. EMG is an electrodiagnostic medicine technique for evaluating and recording the electrical activity produced by the muscles. This was planned to serve as the controller interface for the legs allowing the user to steer a training or rehabilitation game via gestures (e.g., by the Kinect sensor) and leg movements. After the initial implementations and tests in TUM’s laboratory, the results showed immense amounts of noise when reading the EMG signal over the clothes. As a result, the project team planned to change the approach with the sensor electrodes and read the user activity from different sensors (e.g., touch sensors as mentioned above). Afterwards, such inputs can be used to steer a training or rehabilitation game via foot gestures. Additionally, it will implement early detection, monitoring, and activation for the elderly.

Figure 3-8 Activity monitoring sensors used in PI²U-Stander

Regarding the sensors and PI²Us development in the REACH project, the first set of prototypes of these systems were designed and implemented. Additionally, the current functionality states of these prototypes are mentioned as follows (as of the beginning of 2019):

- ECG Sensing: 95% implemented, under refinement
- Thermal Camera: 95% implemented, under refinement
- Pressure Mattress: 95% implemented, under refinement
- Kinect for Motion Detection: 95% implemented, under refinement
- Alreh Medical Step Counter: 95% implemented, under refinement
- PI²U-Bed: 70% implemented, under development and refinement
- PI²U-MiniArc: 95% implemented, under refinement
- PI²U-SilverArc: 90% implemented, under refinement
- Breath Frequency Monitoring - Fusion of Thermal Camera and Pressure Mattress: 25% implemented, under development
- Blood Pressure Measurement using ECG sensing: 40% implemented, under development

Regarding the data collection, data annotation and data analysis, many details and issues were discussed and aligned between TUM, SK and FIAIS over weekly/biweekly conference calls. The main points and conclusions of these discussions are summarized below:

- It was decided to monitor the following major points: (1) physical activity, (2) liquid input, (3) eating habits, and (4) hygiene activities.
- In order to implement monitoring of these activities in the first data collection round, the following sensors were used: (1) SmartCardia wearable sensor, (2) Pressure Mattress, (3) Activpal accelerometer wearable sensor, (4) Myoband Arm EMG Sensor, and (5) Cameras (only used for the Data Annotation proving, not for data collection).

The implementation/execution timeline for data collection is executed or planned as below:

- First data collection at TUM: October 5th to 11th, 2018
- Second data collection at SK: February 2019
- Running demonstration at Lyngby: May 2019

So far, the overall testing of the PI²Us was successful. Based on the feedback from the testing, the PI²Us will be further revised and eventually resemble the proposed furniture design. After the early prototype testing of functionality and the first data collection, TUM proposed a design of a modularized apartment integrating all PI²Us and key technologies in REACH's four Touchpoints to create a total interior living and care environment for elderly users. This design demonstrates the comprehensive REACH platform and can be adapted and implemented partially or entirely to different use case settings in an easy and rapid manner.

3.2 Completed methodology testing using data collection to generate a database

A data collection trial was executed at TUM-br2 test apartment including TUM, SK, and FIAIS. The details of this trial were presented in **Chapter 2** of **Deliverable D26** (Final mock-up version of REACH system) to some extent. The main objectives of this data collection trial are the following:

- Collecting initial data (trained data) in order to test the data annotation software
- Collecting initial data for development support of machine learning algorithms
- Defining detailed steps before running data collection in a clinical environment
- Preparing sufficient and comprehensive information for the application to ethics commission before the clinical test
- Based on the created understanding, proper task division between partners from different backgrounds
- Identifying loopholes and risks to improve efficiency for the clinical setup test
- A pre-integration was executed, to be prepared for the data collection in a clinical setup of the SK

In order to implement this trial, the team of TUM, SK and FIAIS went through extensive communication for 2-3 months and worked out all the prerequisite technical details and understandings from a sensing and monitoring point of view, clinical point of view, and data analysis point of view. This trial was implemented with an approach to fulfil the requirements of all contributing partners and REACH project and objectives. Furthermore, the most important objective was to support FIAIS with data collection and annotation. In order to realize the data annotation and clarify the data classifiers for specific events, the ELAN software was tested and proved its functionality.

For this trial several types of sensors (ambient and wearable) were utilized, namely, ActivPal (accelerometer sensor), SmartCardia wearable sensor, MyoBand EMG sensor, Mobile phone (gyroscope), Pressure Mattress for micro mobility monitoring, and cameras in order to use the feed for data annotations. These sensors were implemented in order to monitor four major activity aspects: eating aspect, drink intake aspect, hygienic aspect and the general aspect of mobility activities at home.

In order to have a proper video feed for data annotation five cameras were utilized, including four cameras mounted on the walls and one hand camera. **Figure 3-9** shows the location of the mounted cameras and moving directions of the hand camera.

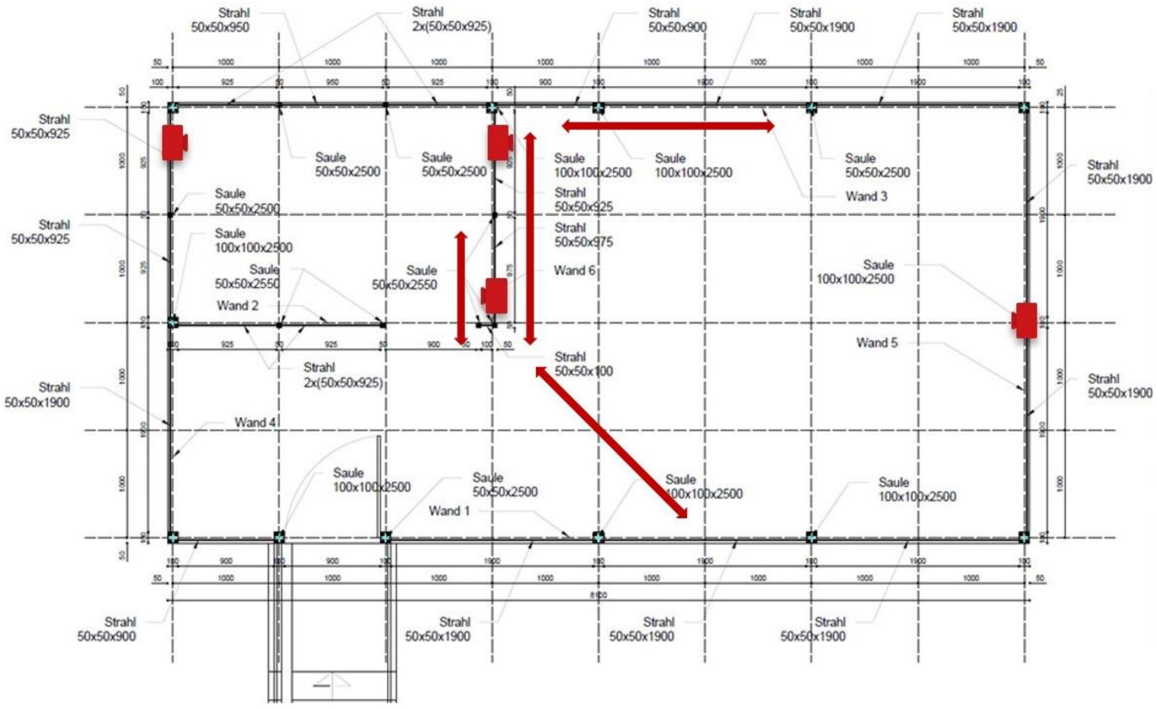


Figure 3-9: Location of mounted cameras and directions of the hand camera

Additionally, the wearable sensors were attached to the test person according to **Figure 3-10**.

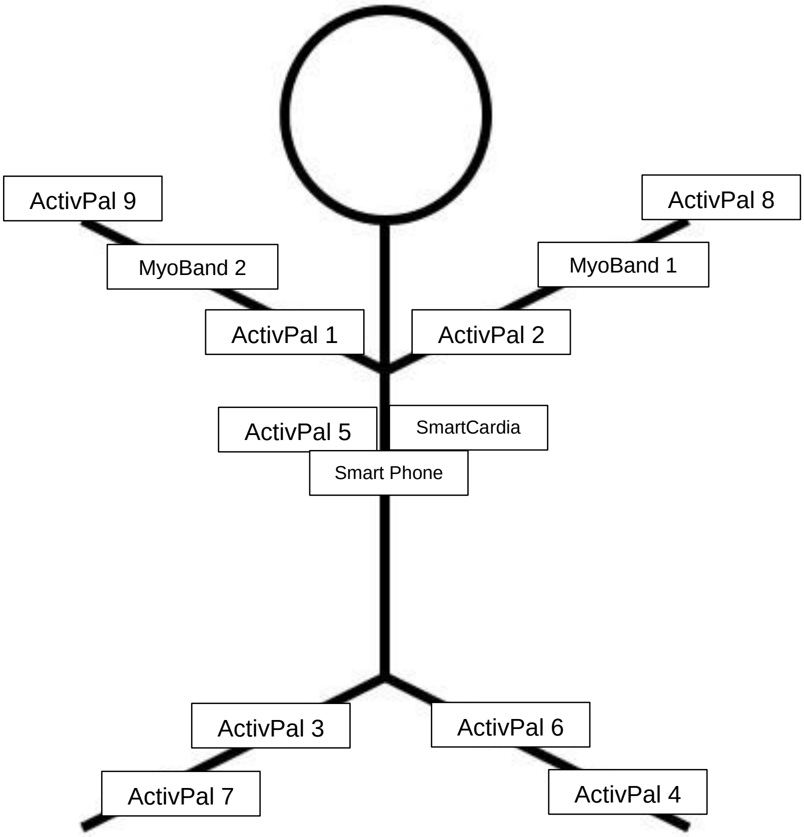


Figure 3-10: Positioning of the wearable sensors

The figures below provide an overview of the performed test (see **Figure 3-11** to **Figure 3-13**).

Figure 3-11: Attaching sensors to the body of the test persons

Figure 3-12: Running the test – example of hygiene aspect: washing hands and brushing teeth

Figure 3-13: Running the test – example of hygiene aspect: washing hands and brushing teeth

This trial had two data collection approaches/runs for each test subject: 1) ADL: Activities of Daily Living which means the test subject will follow a series of actions based on a previously decided protocol called Data Acquisition protocol. 2) DR: Drill Run which means the test subject will perform fewer series of actions (compared to ADL) but will repeat each of these actions several times. For each test subjects, four ADLs and two DRs were performed and data was collected.

This trial had major results in three different aspects:

- **Data analysis aspect:** As a result of this workshop and in a close cooperation between SK, FIAIS and TUM, a large data set was recorded. This data set was initially examined to make sure that the data was properly collected, and time stamped. Furthermore, the data was initially proved to assure possibility of annotating this data. After the data is annotated (marked), the proper classifiers can be generated which will lead to developing proper machine learning algorithms.

- **Clinical/Medical aspect:** As a result of this workshop and based on the collected experience, SK (the clinical/medical) partner are in the application process with the ethics commission. Once this application is approved by the ethics commission, SK will have permission to perform and implement a medical/clinical trial at their clinic. Basically, this trial is also setting the stepping stone for the SK to implement the trial.

- **Sensing and Monitoring aspect:** In the process of preparing for this workshop and as its result, a cross sectional (including ambient and wearable) sensing system was implemented at the br2 test apartment. Furthermore, a local server (not connected to the open internet) was developed in order to automatically and locally store the collected data. This implementation sets the stepping stone for TUM in implementing the system at SK in 2019.

3.3 Methodology tests using data collection to generate a database

After the initial trial executed at the TUM-br2 test flat, the plan is to implement the same test using real patients/elderly citizens at SK. After this test, the FIAIS will be able to adapt/adjust the machine learning algorithms (data classifiers) to work properly on the data collected from the elderly citizens. In order to implement this trial at SK site and to include real patients, the team needs permission from the ethics commission. At the moment, the TP2 team is in the application process with the ethics commission. As soon the application is accepted, this trial will be implemented at SK. The exact planning and scheduling will be finalized upon completion of the ethics application.

Furthermore, it is planned to implement a complete REACH exhibition at Lyngby's site in Copenhagen in May 2019. This event will take place from 13th May 2019 until 16th May 2019. An estimated schedule of this event is as follows:

- 13th May, 2019: Joint preparation
- 14th - 15th May, 2019: Integrational REACH Conference + demo/exhibition. This will include a group of gerontechnology experts to participate, visit, and provide feedback to the REACH consortium. Additionally, it is planned to have open doors for the elderly citizens in the Lyngby/Copenhagen area who would like to attend this exhibition.
- 16th May, 2019: Consortium/Work Group Meeting

4 Planned field tests of the PI²Us

Field tests are a crucial tool in terms of validating the PI²Us in a real-life environment in REACH. In addition to aforementioned laboratory-based testing activities, field tests in real-life environments are scheduled and will be conducted in the near future as well.

4.1 Test 1: testing/demonstration of selected PI²Us in the naturalistic environment in Lyngby

Testing/demonstration of selected PI²Us (i.e., PI²U-MiniArc and PI²U-SilverArc) will be conducted in the naturalistic environment in Lyngby (in May 2019) in the context of smart homes for the elderly (Touchpoint 4). **Figure 4-1** below demonstrates a possible simulation of the modularized smart home environment in Lyngby, Denmark, in which the selected PI²Us are deployed.

Figure 4-1: A possible simulation of the modularized smart home environment including all PI²Us in Lyngby, Denmark

4.2 Test 2: PI²U-Bed and patient environment testing at SK/Touchpoint 2

The PI²U-Bed and patient environment testing at SK/Touchpoint 2: in summer 2019, the project team will build up a mock-up of the patient room at SK (i.e., Schön Klinik Bad Aibling), including a second prototype of the PI²U-Bed. A possible simulation of the modularized patient room is demonstrated below (see **Figure 4-2**). The physical elements will be tested in smaller scale over days in a simulated environment at SK, and the sensing elements will be tested over weeks in the real rooms and wards of SK.

Figure 4-2: A simulation of the modularized patient room to be implemented in Schön Klinik Bad Aibling

5 Summary and conclusions

This deliverable report reports the outcome of the construction of functional or partly functional prototypes/mock-ups of Personalized Interior Intelligent Environment Units (PI^{2}Us) for demonstration and testing purposes, mainly associated with **Task T5.4**.

Chapter 1 of this document provided an overview of the background of this task and the relation of this task to other tasks in **WP5**, to other work packages, and to the larger framework of the REACH project.

Chapter 2 sets out the details of the progressive development of the PI^{2}Us from early concepts to the current prototyping and testing stage. First of all, the prototyping method and developing process are introduced. Secondly, a number of tools and facilities including the mechatronics workshop, the functionality and laboratory testing tools, the test flat, and the field test settings are reviewed. Furthermore, the modularized patient apartment concept and relevant PI^{2}Us are reviewed, which were previously introduced in detail in **Deliverable D22**.

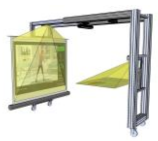
In **Chapter 3**, the subsequent lab-based testing is detailed. This includes both testing activities that have already been carried out (e.g., the functionality testing and the laboratory testing in TUM's test flat) and planned testing activities for either early stage validation (e.g., in Schön Klinik Bad Aibling, Germany) or final demonstration in a naturalistic test environment (e.g., in DTU/Lyngby, Copenhagen).

Finally, **Chapter 4** summarizes the key results of this report. Furthermore, in the following sections, it will put the different prototypes in perspective to the respective Touchpoints and explain how the selected PI^{2}Us are integrated with REACH Engine functionality.

5.1 Outline of mock-up/prototyping activity in each Touchpoint

In summary of this report, the table below (**Table 5-1**) indicates the ongoing or completed activities of the prototypes involved in each Touchpoint.

Table 5-1: Outline of mock-up/prototyping activity per Touchpoint

Mock-up/ Prototype	TP1	TP2	TP3	TP4
PI^{2}U-SilverArc 		• Prototype building • Functionality testing	• Functionality testing	
PI^{2}U-MiniArc 		• Prototype building • Functionality testing		• Functionality testing
PI^{2}U-Bed		• Prototype building • Functionality testing		

				
PI²U-Stander 	• Prototype building • Functionality testing	• Prototype building • Functionality testing • Endurance testing of the stand-up counter		
ActivLife Gaming Plat-form 	• Prototype building • Functionality testing			
Interactive Cooking Table 			• Prototype building • Functionality testing	
Playware Moto Tiles 		• Functionality testing		• Prototype building • Functionality testing • Usability test-ing

Furthermore, the graphic on the next page (see **Figure 5-1**) demonstrates how various PI²Us in REACH are connected to the REACH Touchpoints and Engine concept, and the REACH toolkit.

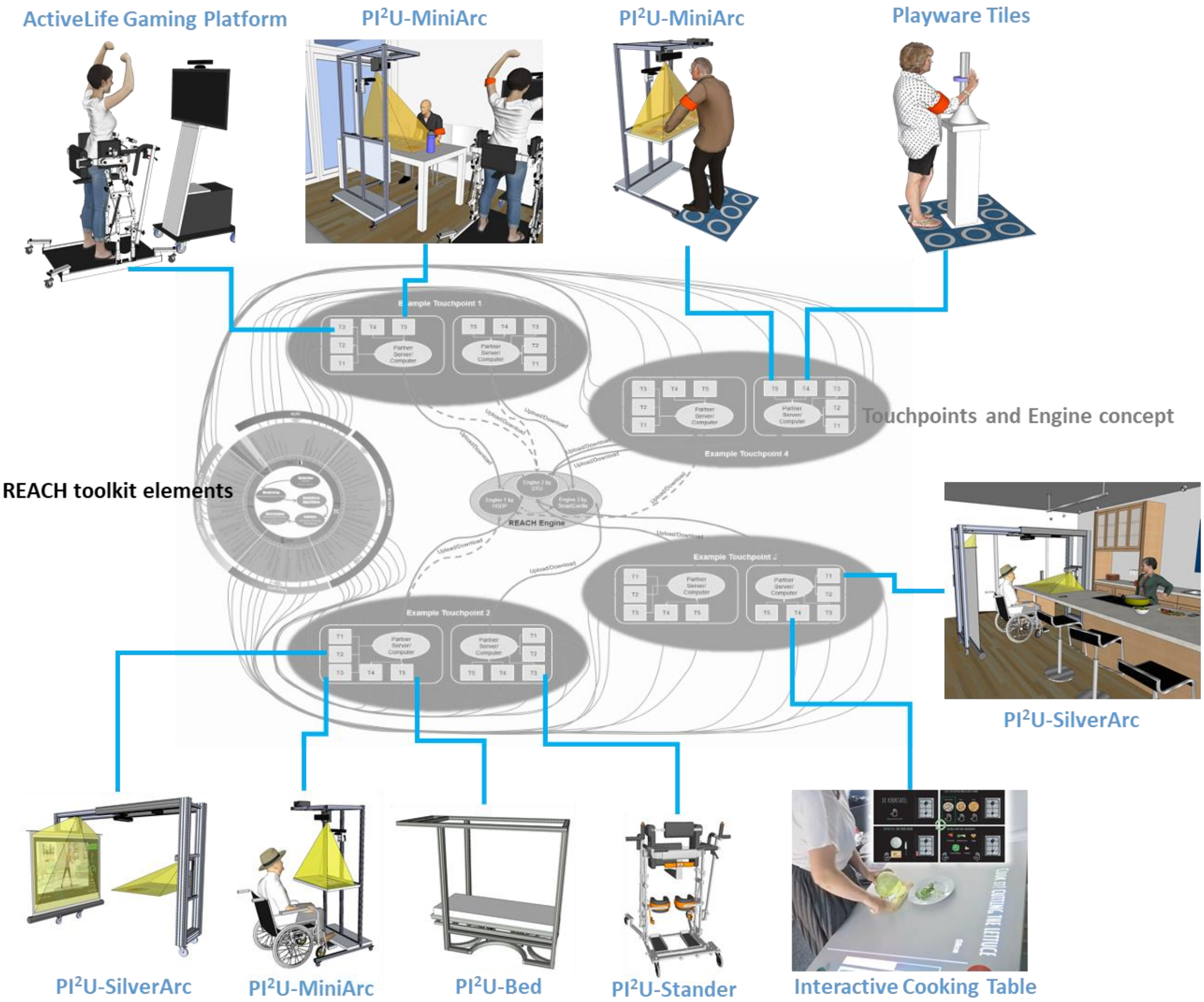


Figure 5-1: Various PI²U prototypes linked to Touchpoints & Engine concept and the REACH toolkit

Reference

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