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Human-Centred Research & Design for Inclusive Mobility. Sections A & B

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Human-Centred Research & Design for Inclusive Mobility

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Introduction

The French version of this document is initially intended for future research candidates at [Université Polytechnique Hauts-de-France \(UPHF\)](https://www.uphf.fr/en/discover-university)¹, as well as the PhD students at LAMIH ([Laboratory of industrial and human automation, mechanics and computer science](https://www.uphf.fr/lamih))² who wish to apply a human-centred approach to their work, especially regarding the design of technologies dedicated to human mobility or handicapped persons. However, the English version can also be useful to the students of the [Erasmus+ European University EUNICE](https://eunice-university.eu/tag/erasmus/)³ by way of REUNICE H2020 project⁴. In short, this work can be of interest to anyone who would like to learn more about human-centred approaches.

Such approaches are indeed at the heart of [Industry 5.0](#): according to the European Union, the European industry will serve society better by complementing the techno-economic vision of Industry 4.0 (i.e., focused on digitalisation, AI technologies, efficiency and flexibility of production) by the Industry 5.0 perspective which features human⁵-centricity, sustainability and resilience as core values⁶. Concretely, the [students of today – who](#)

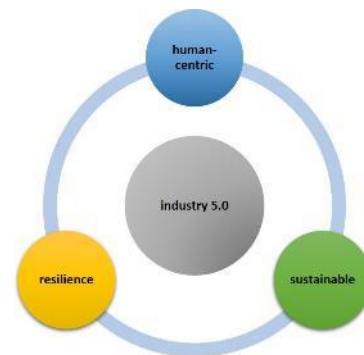


Figure 1 The three pillars of Industry 5.0, to serve society better. Source: European Commission, 2021, *Industry 5.0* (p. 13). <https://doi.org/10.2777/308407>

[will be tomorrow's innovators](#) – should start imagining research to be carried out and technologies to be invented, thinking in terms of “human,” or even humanity, as well as thinking “useful and nonharmful” to the planet and her inhabitants in both near and distant future⁷.

The present work aims to [introduce students to human-centric research and design](#) through the human factors approach and the users-centred approach. Even though the topics of human mobility and disability are often mentioned, the described approaches are applicable to other domains.

¹ Université Polytechnique Hauts-de-France : <https://www.uphf.fr/en/discover-university> (accessed 21/06/2022)

² LAMIH UMR CNRS 8201: <https://www.uphf.fr/lamih> (id.)

³ EUNICE: <https://eunice-university.eu/tag/erasmus/> (accessed 17/05/2022)

⁴ REUNICE: <https://cordis.europa.eu/project/id/101035813> (id.)

⁵ Not only workers and operators in manufactures, but also individuals, people, communities in general.

⁶ European Commission (2021). *Industry 5.0* (First edition). Luxembourg: Publications Office of the European Union. <https://doi.org/10.2777/308407>

⁷ This idea is not new, see the imperative of responsibility proposed by the Philosopher Hans Jonas (1973). *Technology and responsibility: Reflections on the new tasks of ethics. Social Research*, 40(1), 31-54. <https://www.jstor.org/stable/40970125>



Figure 2 LAMIH CISIT. Source : Google Maps, accessed 7/12/2021

LAMIH UMR CNRS 8201 is a joint research unit of CNRS⁸ and UPHF. The laboratory – a member of the CARNOT network through CARNOT ARTS⁹ – is structured into 4 departments (i.e., *Automation, Mechanical engineering, Computer Science, and Human & Life Sciences*) and the transversal axis of Human

Mobility and Disability (MH2)¹⁰. They all are committed to the fields of transport and mobility. It is an inclusive mobility insofar as the end users of the studied or designed technological systems include diverse populations such as tram/train drivers, handicapped persons, elderly people, sportsmen and women, pedestrians, people with mobility issues (e.g., lower limb amputees).

For example, MH2 aims to make the environment more accessible to people with mobility issues, limit the degradation of their mobility, design technological assistance which is adapted to their state, and improve their condition regarding

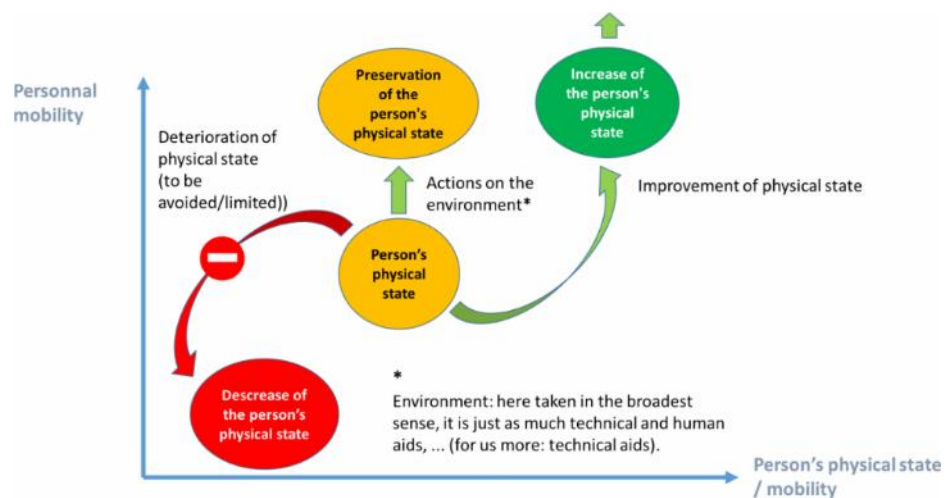


Figure 3 Goals of the transversal ‘human mobility and disability’ axis. Source: <https://www.uphf.fr/LAMIH/en/description> (accessed 17/05/2022)

their mobility disability (Figure 3); the related challenges are the fall of the elderly, the design of intelligent wheelchair and robotic ortheses¹¹.

⁸ CNRS is the French National Centre for Scientific Research: <https://www.cnrs.fr/en/cnrs> (accessed 17/05/2022)

⁹ The Carnot label: <https://www.instituts-carnot.eu/en/carnot-label> (id.)

¹⁰ LAMIH organisation: <https://www.uphf.fr/LAMIH/en/organisation> (accessed 03/05/2022)

¹¹ MH2 Axis: <https://www.univ-valenciennes.fr/LAMIH/en/description> (accessed 17/05/2022)

The two key issues of the Department of Human & Life Sciences (SHV)¹² are to improve and preserve mobility, thus contributing to favouring well-being and social integration. Figure 4 shows the global methodological approach that supports the research challenge to analyse and model how humans control on their activities, from the perceptual level to the motor action level, passing through the decisional level.

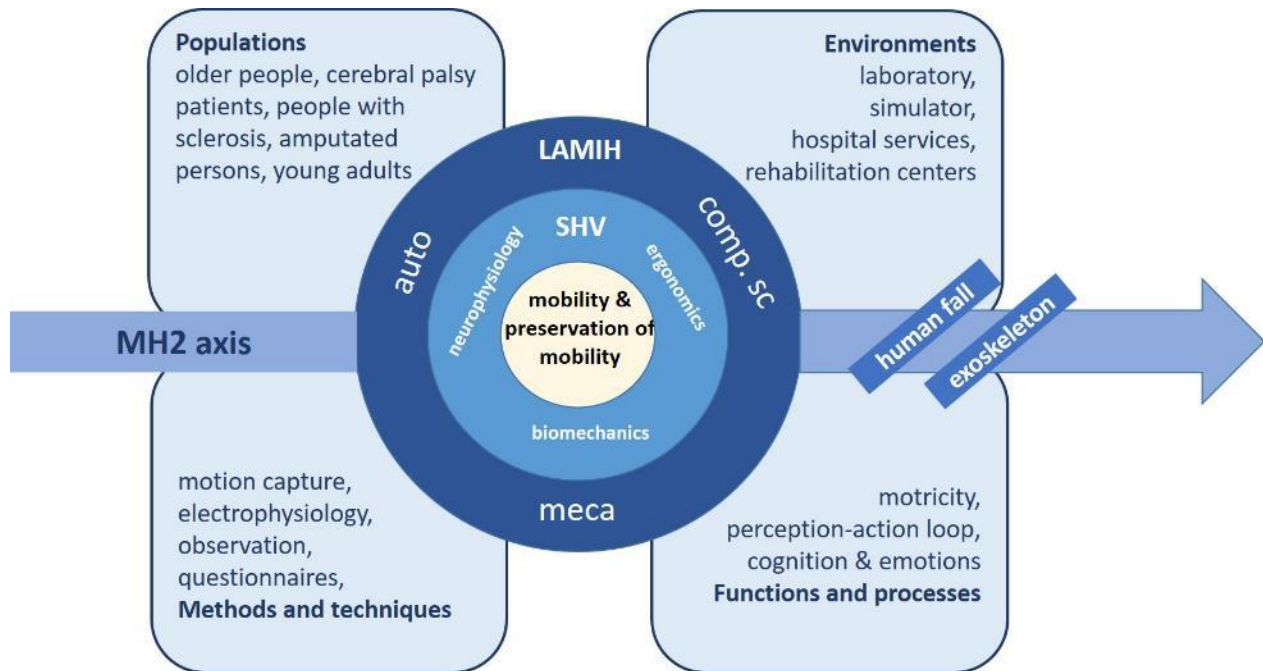


Figure 4 The global methodological approach of the Department of Human & Life Sciences, showing the diversity of research environments and populations (figure adapted from <http://www.uphf.fr/LAMIH/fr/themes-de-recherche-shv>, accessed 03/05/2022)

As for Computer science¹³, the Department is an expert at designing applications dedicated to mobility and personalized assistance for disabled people ; the Department of Automation and control¹⁴ works on, among other topics, automated driving, wheelchairs, and the fall of the elderly. It is important to emphasise that **human fall is a common issue in the four departments** including Mechanical engineering¹⁵.

All those examples show the involvement of LAMIH in research and design for inclusive mobility. The underlying strategy is, of course, shared with **UPHF, a sustainable and inclusive university**¹⁶, insofar as two of its three identity axes are: *Intelligent, safe and sustainable*

¹² SHV Department: <https://www.uphf.fr/LAMIH/en/human-and-life-sciences-shv> (accessed 18/05/2022)

¹³ Computer Science Department: <https://www.uphf.fr/LAMIH/en/computer-science> (accessed 19/05/2022)

¹⁴ Automation Department: <https://www.uphf.fr/LAMIH/fr/automatique> (id.)

¹⁵ Mechanical engineering Department: <https://www.uphf.fr/LAMIH/en/research-topics-mechanic> (id.)

¹⁶ <https://www.uphf.fr/en/universite/decouvrir-luniversite/sustainable-and-inclusive-university> (accessed 22/06/2022)

transport, mobility and urban systems; and Engineering for health, disability and silver autonomy¹⁷. As a result, both LAMIH and UPHF contribute to achieving the United Nations’s Sustainable Development Goals (SDGs) through the Goal no.3 to “ensure healthy lives and promote well-being for all at all ages” and the Goal no. 11 to “make cities and human settlements inclusive, safe, resilient and sustainable,” and which includes sustainable transport.



Figure 5. Source: https://sdgs.un.org/#goal_section

Furthermore, UPHF is closely connected with: the French Technological Research Institute IRT Railenium¹⁸ for railway infrastructure, equipment and systems; the Sustainable Transport Mobility Institute¹⁹ ; the Transalley Technology Park²⁰ ; and the Gyrovia experimentation and demonstration track²¹ (Figure 6). Gyrovia – which includes a wheelchair track – is open to LAMIH demonstrators.



Figure 6 The Gyrovia track. Source: <https://www.transalley.com/transalley/presentation/gyrovia> (accessed 03/05/2022)

LAMIH is thus part of an “ecosystem” articulated around mobility, the laboratory being, moreover, a member of the CNRS Research Federation ‘Land Transport and Mobility’ (FR 3733)²², and many of its platforms are dedicated to transport and mobility²³.

The present document is divided into four great sections. The first section gives a brief overview of LAMIH platforms and projects about mobility and the maintaining of mobility. Section B describes two human-centred approaches for research and design projects, namely the human factors approach and the users-centred approach. Section C examines the research methods and techniques peculiar to these two approaches. The last section is about the exploitation of research results.

The present document is divided into four great sections. The first section gives a brief overview of LAMIH platforms and projects

¹⁷ <http://www.uphf.fr/luniversite-polytechnique-hauts-de-france> (accessed 03/05/2022)

¹⁸ Railenium: <https://railenium.eu/railenium/#presentation> (accessed 19/05/2022)

¹⁹ IMTD: <https://imtd.fr/en/> (id.)

²⁰ Transalley: <https://www.transalley.com/en/transalley/about/the-technology-park> (id.)

²¹ Gyrovia : <https://www.gyrovia.fr/> (id.)

²² <http://www.frtm.fr/>

²³ See: <https://www.uphf.fr/LAMIH/en/plateformes> (accessed 25/05/2022)

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Human-Centred Research & Design for Inclusive Mobility.

Section A – Platforms, Technologies and Projects

This section briefly presents the technologies that are utilised at LAMIH regarding transport, mobility and disability, particularly those used for human-centred research and design purposes. The section is thus heterogeneous: it includes full-scale simulators but also describes projects of applications dedicated to mobility and/or disability. A representative reference of each related work is provided. Section A also comprises a chapter on virtual reality (VR) ends the section, because of its importance for simulation.

A.1 Platforms and simulators

A.1.1 Definitions

The simulators described in this section are kinds of “*apparatus or system that generates/reproduces an imitation of an operational environment or real process across a period of time*”; “*they provide a safe, accessible environment, for the purposes of personal training/assessment; research, evaluation of system design/development*” (Roberts et al., 2020, p. 510²⁴). Simulation is a technique (not a technology); it is “*the imitative representation of the functioning of one system or process by means of the functioning of another*”²⁵.”

A.1.2 Examples of transport- and mobility-related simulators at LAMIH

They range from desktop simulators to full-scale simulators.

A.1.2.a Air traffic simulator

The goal of **AMANDA**²⁶ project was to **tackle human-machine cooperation** through dynamic tasks allocation between air-traffic controllers and a support tool that was able to resolve some conflicts between aircrafts²⁷. The desktop simulator (Figure 7) has been improved over time by

²⁴Roberts A.P.J, Stanton N.A., Plant K.L., Fay D.T., Pope K.A. (2020). You say it is physical, I say it is functional; let us call the whole thing off! Simulation: an application divided by lack of common language. *Theoretical Issues in Ergonomics*. <https://doi.org/10.1080/1463922X.2019.1683913>

²⁵ <https://www.merriam-webster.com/dictionary/simulation> (accessed 24/05/2022)

²⁶ AMANDA: Automation & MAN-machine Delegation of Action

²⁷ Debernard S., Cathelain S., Crevits I., Poulain T. (2002). AMANDA Project: Delegation of tasks in the air-traffic control domain. *Proceedings of the 5th International Conference on Designing Cooperative Systems (COOP 2002)* in: Blay-Fornarino

Prof. Debernard, Dr. Poulain and successive PhD students. It is still used as a pedagogical tool at INSA Hauts-de-France²⁸.



Figure 7 AMANDA simulator. Source : © François JANNIN/CNRS, https://images.cnrs.fr/photo/20060001_1032 (accessed 06/05/2022)

- Serge Debernard, Benoît Guiost, Thierry Poulain, Igor Crévits, David Annebicque, Patrick Millot (2009). Integrating human factors in the design of intelligent systems: An example in air traffic control. *International Journal of Intelligent Systems Technologies and Applications*. <https://doi.org/10.1504/IJISTA.2009.026088>

A.1.2.b PSCHITT Platform

The Hybrid and Inter-modal Collaborative Simulation Platform in Land Transport²⁹ has been co-funded by: the European Union through the European Regional Development Fund³⁰, the State, and Région Hauts-de-France (€1.5 million). PSCHITT is composed of a Rexroth hexapod motion platform and interchangeable cabins, which enables various kinds of simulators, for example, for train driving, pedestrian and wheelchair (Figure 8). Two engineers in automatic control - Thierry Poulain and Gerald Conreur - design and operate PSCHITT, manage the scheduling of experiments and thus contribute to the related research.

M., Pinna-Dery A.M., Schmidt K., Zaraté P. (eds), *Frontiers in artificial intelligence and application*, pp. 173-190. Amsterdam: IOS Press

²⁸ <https://www.groupe-insa.fr/en/discover/insa-campuses/insa-hauts-de-france> (accessed 25/05/2022)

²⁹ <https://www.uphf.fr/LAMIH/en/PSCHITT> (id.)

³⁰ <https://www.europe-en-france.gouv.fr/en/european-funds/european-regional-development-fund-ERDF> (id.)



Figure 8 PSCHITT Platform. Source: <https://www.uphf.fr/LAMIH/en/PSCHITT> (accessed 25/05/2022)

A.1.2.b.i PSCHITT-Colibri

Initially developed within the **SIEGES-COLIBRI** project³¹, PSCHITT-Colibri (Figure 9) is used to analyse the postural stability in an airline seat, regardless of passengers' disability type, age, or weight. A video demonstration is available³².

- Victoria Spartacus, Mathias Blandeau, Ciska Molenaar, François Gabrielli, Dany Gagnon, Philippe Pudlo (2019). On-board lived experience of manual wheelchair users: Aircraft seat satisfaction level and potential solutions to improve comfort and accessibility. *International Journal for Studies on Children, Women, Elderly and Disabled People*. https://www.ijcwed.com/wp-content/uploads/2019/05/PiCCWED7_204amanda-New.pdf

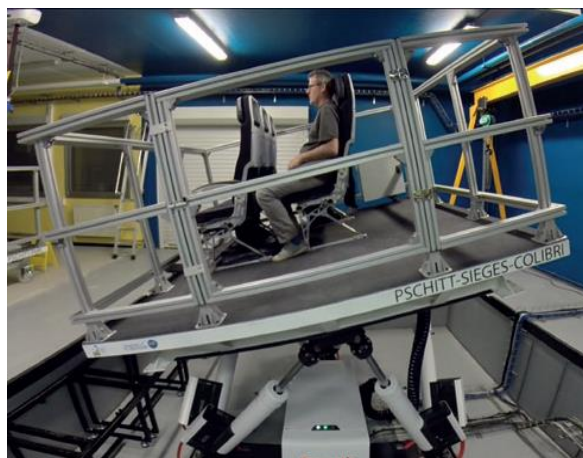


Figure 9 PSCHITT-Colibri. Source : https://www.uphf.fr/LAMIH/sites/fr.LAMIH/files/pdf/General/lamih_news_-_decembre_2020_web.pdf (accessed 03/05/2022)

³¹ <https://www.uphf.fr/LAMIH/en/Colibri> (accessed 25/05/2022)

³² https://www.uphf.fr/LAMIH/sites/fr.LAMIH/files/video_colibri_1080p_aac.mp4 (id.)

A.1.2.b.ii PSCHITT-PMR

PSCHITT-PMR³³ (Figure 10) enables researchers to study and improve the mobility and safety of people with reduced mobility. For example, the **CapaCITIES** project³⁴ aims to **quantify the biomechanical costs of urban wheelchair travel** in order to help users choose paths that preserve their upper limbs.

- Toufik Bentaleb, Viet Thuan Nguyen, Chouki Sentouh, Gérald Conreur, Thierry Poulain, Philippe Pudlo (2020). A real-time multi-objective predictive control strategy for wheelchair ergometer platform. In: *Proceedings of the 2019 IEEE International Conference on Systems, Man and Cybernetics (SMC)*, [https://doi-org.ezproxy.uphf.fr/10.1109/SMC.2019.8914220](https://doi.org/ezproxy.uphf.fr/10.1109/SMC.2019.8914220)



Figure 10 PSCHITT-PMR. Source : <https://www.uphf.fr/LAMIH/fr/PSCHITT-PMR> (accessed 03/05/2022)

A.1.2.b.iii PSCHITT-RAIL



Figure 11 PSCHITT-Rail. Source : <https://hal.archives-ouvertes.fr/hal-01854846> (accessed 03/05/2022)

PSCHITT-Rail³⁵ (Figure 11) is a train/tram driving simulator that enables: i/ train and tram drivers to test new assistance systems in various situations and ii/ researchers to study their impact on driver performance. For example, the **ECOVIGIDRIV** project³⁶ aims **to investigate new functionalities for energy-efficient driving** and new modes of human-machine interaction.

- Salvatore La Delfa, Simon Enjalbert, Philippe Polet, Frédéric Vanderhaegen (2016). Eco-driving command for tram-driver system. *IFAC PapersOnLine*. <https://doi.org/10.1016/j.ifacol.2016.10.616>

³³ <https://www.uphf.fr/LAMIH/en/PSCHITT-PMR> (accessed 25/05/2022)

³⁴ <https://www.uphf.fr/LAMIH/en/biomechanical-cost-quantification-wheelchair-accessible-cities> (id.)

³⁵ <https://www.uphf.fr/LAMIH/en/PSCHITT-Rail> (id.)

³⁶ <https://www.uphf.fr/LAMIH/en/economic-and-vigilant-rail-driving> (id.)

A.1.2.b.iv PSCHITT-Pedestrian

Based on a treadmill (Treadmetrix®) and virtual reality, PSCHITT-Pedestrian enables researchers to analyse human locomotion in lab studies with different situations of walking/running.



Figure 12 The Treadmetrix® treadmill of PSCHITT-Pedestrian

- Marie Seeman, Laura Wallard, Valentin Ruiz, Christophe Gillet, Sébastien Leteneur, Emilie Simoneau (2022). Is treadmill walking biomechanically comparable to overground walking? A systematic review. *Gait & Posture*. <https://doi.org/10.1016/j.gaitpost.2021.11.009>

A.1.2.c Human movement analysis platform

The LAMIH platform dedicated to human movement analysis is a large room (225m²) equipped with a 5-metre track, 2 motion capture systems and 6 Kistler force platforms (Figure 13).

Locomotion collected data with PSCHITT-Pedestrian are globally the same as when using the human movement analysis platform: spatio-temporal parameters, kinematic and kinetic data, electrical neuromuscular activity. Data collection and analysis are carried out by the engineer in biomechanics Christophe Gillet with his team of Master and PhD students.

- Sébastien Leteneur, Emilie Simoneau, Christophe Gillet, Yoann Dessery, Franck Barbier (2013). Trunk's natural inclination influences stance limb kinetics, but not body kinematics, during gait initiation in able men. *PloS one*.
<https://doi.org/10.1371/journal.pone.0055256>



Figure 13 The LAMIH platform for human movement analysis

A.1.2.d MissRail® and InnoRail

The MissRail® rail simulation platform (Figure 14) and InnoRail with immersive helmet are tools dedicated to railway-related research and training developed at UPHF.



Figure 14 Simulation with MissRail® of a situation of potential collision. Source: <https://www.uphf.fr/LAMIH/fr/plateforme-multiutilisateur-multimodale-et-multifonction-de-simulation-pour-la-recherche-et-la> (accessed 03/05/2022)

- Frédéric Vanderhaegen (2021). Pedagogical learning supports based on human–systems inclusion applied to rail flow control. *Cognition, Technology & Work*.
<https://doi.org/10.1007/s10111-019-00602-2>

A.1.2.e SHERPA

The SHERPA dynamic driving simulator – co-funded by the European Regional Development Fund, the State, and Région Hauts-de-France – is used for research projects involving the [development and prototyping of cooperative driver assistance systems](#)³⁷.

The engineer in automatic control Jérôme Floris (Figure 15) is the responsible for the SHERPA



Figure 15 The experiment control room of SHERPA platform .Source : © François JANNIN/CNRS Photothèque, https://images.cnrs.fr/photo/20060001_1039 (accessed 03/05/2022)

platform; he ensures with Philippe Simon (engineer in automatic control too) the implementation of test means, the planning and realisation of the evolution of SHERPA, the scheduling of experiments, thus contributing to the related research works.

➔ It is important to underline that the goal of using SHERPA is to contribute to designing automated cooperative driving, and not to develop autonomous vehicles where the driver intervention is not mandatory: research with SHERPA underlies that the human driver is still in the control loop.

The goal of **CoCoVeA** (Driver-Vehicle Cooperation for Automated Driving)³⁸, a project funded by the French National Research Agency (ANR)³⁹ is to develop a cooperative architecture between drivers and assistance systems for automated driving (sharing of vehicle control).

- Mohamed Amir Benloucif, Chouki Sentouh, Jérôme Floris, Philippe Simon, Jean-Christophe Popieul (2019). Online adaptation of the level of haptic authority in a lane keeping system considering the driver's state. *Transportation research part F. Traffic psychology and behaviour*. <https://doi.org/10.1016/j.trf.2017.08.013>

³⁷ <https://www.uphf.fr/LAMIH/en/SHERPA> (accessed 25/05/2022)

³⁸ <https://www.uphf.fr/LAMIH/en/automated-vehicles-and-driver-assistance-systems> (accessed 20/05/2022)

³⁹ <https://anr.fr/en/anrs-role-in-research/about-us/missions/> (id.)

A.1.2.f Cooperating Automated Vehicle Demonstrator

The DS7 Cooperating Automated Vehicle demonstrator⁴⁰ (Figure 16) is used to validate work in the field of man-machine cooperation, particularly on aspects of shared control between the driver and the automated systems in relation to the driver's state. Studies are first carried out on SHERPA and then transferred to the DS7 vehicle for [validation tests on a test track](#).



Figure 16 LAMIH Cooperation automated vehicle demonstrator. Source: <https://www.uphf.fr/LAMIH/fr/luniversite-se-dote-dun-nouveau-vehicule-dessai-dedie-aux-travaux-de-recherche-sur-la-conduite> (accessed 03/05/2022)

A.1.2.g ITM Platform

The current platform ‘Transport and Mobbility Innovation’ (ITM)⁴¹ – whose technical manager is the engineer in automatic control Sébastien Paganelli – have among others a fully instrumented and automated Citroën C1 designed to develop strategies related to autonomous vehicles (Figure 17) and an instrumented driving simulator fitted for persons with reduced mobility (Figure 18).

The ANR **VOLHAND**⁴² project was carried out within the ITM platform; its goal was to develop [a new generation of electric-power-assisted steering for the elderly and people with reduced mobility](#).

⁴⁰ <https://www.uphf.fr/LAMIH/en/cooperating-automated-vehicle-demonstrator> (accessed 30/05/2022)

⁴¹ <https://www.uphf.fr/LAMIH/en/transport-and-mobbility-innovation> (id.)

⁴² <https://www.uphf.fr/LAMIH/en/steering-wheel-elderly-andor-disabled-people> (id.)



Figure 17 ITM's fully instrumented and automated Citroën C1. Source : <https://www.uphf.fr/LAMIH/en/transport-and-mobility-innovation> (accessed 30/05/2022)



Figure 18 VOLHAND project. Source: <https://www.uphf.fr/LAMIH/en/steering-wheel-elderly-andor-disabled-people> (accessed 30/05/2022)

- Pierre Loslever, Jessica Schiro, François Gabrielli, Philippe Pudlo (2021). Introducing coordination in hand position analysis during a steering wheel-based tracking task using fuzzy sets. *Theoretical Issues in Ergonomics Science*. <https://doi.org/10.1080/1463922X.2021.1983886>

A.1.2.h Pedestrian simulator for urban crossing

A pedestrian simulator was developed for the SEVAP⁴³ project to study the street crossing behaviour of elderly pedestrians.

- Julie Delzenne, Aurore Bourrelly, Cyril Garnier, Janick Naveteur, Eric Watelain (2014). How do healthy older pedestrians walk when they cross the street? *Computer Methods in Biomechanics and Biomedical Engineering* <https://doi.org/10.1080/10255842.2014.931165>



Figure 19 Simulator-based system for studying street-crossing. Source: Julie Delzenne's doctoral thesis, 2013, UPHF, p. 147, <http://www.theses.fr/2013VALE0031> (accessed 03/05/2021)

⁴³ <https://www.uphf.fr/LAMIH/en/seniors-city-foot> (accessed 30/05/2022)

A.2 Technologies dedicated to mobility

A.2.1 Definitions

Medical devices

According to the Regulation (EU) 2017/45 of the European Parliament and of the Council on medical devices⁴⁴:

medical device: “any instrument, apparatus, appliance, software, implant, reagent, material or other article intended by the manufacturer to be used, alone or in combination, for human beings for one or more of the following specific medical purposes: diagnosis, prevention, monitoring, prediction, prognosis, treatment or alleviation of disease; diagnosis, monitoring, treatment, alleviation of, or compensation for, an injury or disability; investigation, replacement or modification of the anatomy or of a physiological or pathological process or state; investigation, replacement or modification of the anatomy or of a physiological or pathological process or state”;

accessory for a medical device: “an article which, whilst not being itself a medical device, is intended by its manufacturer to be used together with one or several particular medical device(s) to specifically enable the medical device(s) to be used in accordance with its/their intended purpose(s) or to specifically and directly assist the medical functionality of the medical device(s) in terms of its/their intended purpose(s)”;

CE marking: the symbol ‘CE’ affixed on a medical device means that the device complies with European Directives and Regulations, notably regarding quality system requirements and safety and reliability requirements. Without this marking, medical devices can neither be made available on the market nor put into service. Researchers and engineers thus have to think about the quality, safety and reliability requirements even before they make concrete an idea of a medical device.



Figure 20 CE marking.

Source : https://ec.europa.eu/growth/single-market/ce-marking_en (accessed 30/05/2022)

Robotic devices

Some medical devices can be categorised into robotic devices. According to the International Organization for Standardization:

robot: “programmed actuated mechanism with a degree of autonomy to perform locomotion, manipulation or positioning”⁴⁵;

autonomy: “ability to perform intended tasks based on current state and sensing, without human intervention”⁴⁵;

⁴⁴Medical devices: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02017R0745-20200424> (accessed 30/05/2022)

⁴⁵ ISO 8373:2021(en) Robotics–Vocabulary: <https://www.iso.org/obp/ui/#iso:std:iso:8373:ed-3:v1:en> (accessed 01/06/2022)

robotic technology: “practical application knowledge commonly used in the design of robots or their control systems”⁴⁵;

robotic device: “mechanism developed with robotic technology, but not fulfilling all characteristics of a robot”⁴⁵;

medical robot: “intended to be used as medical electrical equipment or medical electrical systems. A medical robot is not regarded as an industrial robot or a service robot”⁴⁵;

service robot: “in personal use or professional use that performs useful tasks for humans or equipment”⁴⁵;

personal care robot: “service robot that performs actions contributing directly towards improvement in the quality of life of humans, excluding medical application”⁴⁶;

physical assistant robot: “personal care robot that physically assists a user to perform required tasks by providing supplementation, or augmentation of personal capabilities”⁴⁶.

Villaronga (2016)⁴⁷ noticed the confusing categories in robotics, which has a consequence in terms of regulations: “*if exoskeletons were meant to be robotic devices just to help users in their daily routine (similarly to robotic prostheses), then personal care robots ISO would apply. However, if their aim is to enhance patients’ sanity and they are designed to be used in rehabilitation contexts, the medical devices’ regulation would have to apply*” (Villaronga, 2016, p. 38). [Given the growing importance of robots in today’s society, this may give future PhD students ideas for future transdisciplinary work ...](#)



LAMIH is involved in research related to medical devices and service robotics, particularly through works concerned with mobility and mobility preservation. But LAMIH is also involved in robotic transportation, more precisely, the Department of Automation & control and the current ITM platform with their work on automatic control for automated driving and autonomous cars, and the Department of Computer Science with their work on software for autonomous cars (Figure 21).

⁴⁶ISO 13482:2014(en) Robots and robotic devices–Safety requirements for personal care robots (accessed 02/06/2022)

⁴⁷ Fosch Villaronga E. (2016). ISO 13482: 2014 and its confusing categories. Building a bridge between law and robotics. In: Wenger P., Chevallereau C., Pisla D., Bleuler H., Rodić A. (eds), *New trends in medical and service robots. Challenge and solutions*. Mechanisms and Machine Science. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-30674-2_3



Figure 21 Demonstration of the electric autonomous Navya shuttle at UPHF.
Source: <https://www.uphf.fr/CRISS/universite-et-navya-etendent-leur-cooperation> (accessed 03/05/2022)

A.2.2 Technologies

This chapter broaches the technologies through related projects. It is rather heterogeneous because it includes both medical devices - or potentially medical devices - and applications dedicated to mobility. The variety of projects shows the involvement of LAMIH in research that contributes to the well-being for all at all ages.

A.2.2.a Personalized assistance for people with reduced mobility

The **PA-PMR** project⁴⁸ (*Customization of assistance for persons with reduced mobility*) aimed to develop a system that could estimate the user's intention to propose personalized assistance. The **AutoM-PMR**⁴⁹ project (*Advanced Automatic Control for Mobility of Person with Reduced Mobility*) aimed to develop methodological tools for observation and control integrating human behaviour models for various situations.

⁴⁸<https://www.uphf.fr/LAMIH/en/customization-assistance-persons-reduced-mobility> (accessed 31/05/2022)

⁴⁹ <https://www.uphf.fr/LAMIH/en/autom-prm-advanced-automatic-control-mobility-person-reduced-mobility-prm-ecos-nord-ndeg-m17m02> (id.)

- Guoxi Feng, Thierry Marie Guerra, Lucian Busoniu, Anh-Tu Nguyen, Sami Mohammad (2021). Robust observer-based tracking control under actuator constraints for power-assisted wheelchairs. *Control Engineering Practice*. <https://doi.org/10.1016/j.conengprac.2020.104716>
- Alberto Ortiz, Thierry-Marie Guerra, Victor Estrada-Manzo, Jimmy Lauber (2021). Choosing an Adequate Convex Structure for Controller and Observer Gains in Takagi-Sugeno Control Systems. *IFAC-PapersOnLine*. <https://doi.org/10.1016/j.ifacol.2021.10.035>

A.2.2.b MotoBOTTE

MotoBOTTE is a project based on a patented ergometer⁵⁰ developed at the laboratory. The goal was to develop a hybrid brain computer interface capable of coupling electrophysiological data and biomechanical information in order to produce personalized ankle rehabilitation.

MotoBOTTE also refers to the robot designed for the assisted rehabilitation (Figure 22).

- Juan Arceo, Jimmy Lauber, Emilie Simoneau-Buessinger, Sylvain Cremoux (2018). Nonlinear Convex Control for Robotic Assistive Therapy via LMIs. *Workshop on Assistance and Service Robotics in a Human Environment: From Personal Mobility Aids to Rehabilitation-Oriented Robotics in the International Conference on Intelligent Robots 2018 (IROS 2018)*. <https://hal.archives-ouvertes.fr/hal-01911178>

- Juan Carlos Arceo, Jimmy Lauber, Lucien Robinault, Sebastien Paganelli, Mads Jochumsen, Imran Khan Niazi, Emilie Simoneau, Sylvain Cremoux (2019) Modeling and Control of Rehabilitation Robotic Device: motoBOTTE. In: Masia L., Micera S., Akay M., Pons J. (eds) *Converging Clinical and Engineering Research on Neurorehabilitation III. ICNR 2018. Biosystems & Biorobotics, vol. 21*. https://doi.org/10.1007/978-3-030-01845-0_110



Figure 22 MotoBOTTE. Source : Juan Carlos Arceo Luzanilla. *Assistive Motor Reeducation via Brain Computer Interface for Neurological Deficiencies*, p. 25. UPHF, INSA Hauts-de-France, 2021. <https://tel.archives-ouvertes.fr/tel-03346043>

⁵⁰ <https://uspto.report/patent/grant/10,835,173>

A.2.2.c Lower limb prosthesis

A lower limb prosthesis is prescribed by a doctor to replace any part of the lower limb, and it is the orthoprosthesis who adjusts the prosthesis, supervises the custom manufacturing of it, and follow the progress of its use by the patient (Figure 23). As emphasized by the French [Fondation HOPALE](#)⁵¹, the fitting of a lower limb prosthesis takes the patient's life plane into account, and the family is supported too. This is thus an explicit users-centred approach. See *Section B – Human-centred approaches*.



Figure 23 The fitting of a lower limb prosthesis. Source: <https://hopale-international-care.com/index.php/services/amputee> (accessed 01/06/2022)

LAMIH is involved in the analysis of the locomotion to [quantify the evolution of biomechanical parameters during rehabilitation and follow-up after amputation](#) with the aim of characterizing compensatory strategies and evaluating prosthetic needs. Such work provides concrete aid to clinicians so as to each prosthesis is perfectly adapted to each patient. [RASTAF-ARI](#)⁵² (*Rehabilitation Assisted by Technology for the Functional improvement of Amputee looking at Initial setting of the prosthetic – Action for Anticipative Research*), [GRAAL](#)⁵³ (*Gait Rehabilitation Analysis for Amputee Locomotion*), and [STRAAL](#)⁵⁴ (*Motor modalities developed during usual locomotion in lower limb amputees*) are all research projects based on that expertise.

- Émilie Simoneau-Buessinger, Jennifer M. Jakobi, Anis Toumi, Anne Mathys, Jennifer Bassement, Franck Barbier, Sébastien Leteneur (2019). Does Unilateral Lower Limb Amputation Influence Ankle Joint Torque in the Intact Leg? *Archives of Physical Medicine and Rehabilitation*. <https://doi.org/10.1016/j.apmr.2018.12.023>
- Anis Toumi, Émilie Simoneau-Buessinger, Jennifer Bassement, Franck Barbier, Christophe Gillet, Paul Allard, Sébastien Leteneur (2021). Standing posture and balance modalities in unilateral transfemoral. and transtibial amputees. *Journal of Bodywork and Movement Therapies*. <https://doi.org/10.1016/j.jbmt.2021.05.009>

⁵¹ <https://www.hopale-international-care.com> (accessed 01/06/2022)

⁵² <https://www.uphf.fr/LAMIH/en/rehabilitation-assisted-technology-functional-improvement-amputee-looking-initial-setting-prosthetic> (id.)

⁵³ <https://www.uphf.fr/LAMIH/en/gait-rehabilitation-analysis-amputee-locomotion> (id.)

⁵⁴ <https://www.uphf.fr/LAMIH/en/motor-modalities-developed-during-usual-locomotion-lower-limb-amputees> (id.)

A.2.2.d Exoskeleton

RehabByExo^{55,56} is project that aims to develop an exoskeleton for walking rehabilitation of patients with severe hemiplegia.

- Gaëtan Courtois, Jason Chevie, Antoine Dequidt, Xavier Bonnet, Philippe Pudlo (2021). Design of a rehabilitation exoskeleton with impedance control: First experiments. In: *Proceedings of the 18th International Conference on Informatics in Control, Automation and Robotics*. SCITEPRESS – Science and Technology Publications, Lda. <https://dx.doi.org/10.5220/0010580004690476>

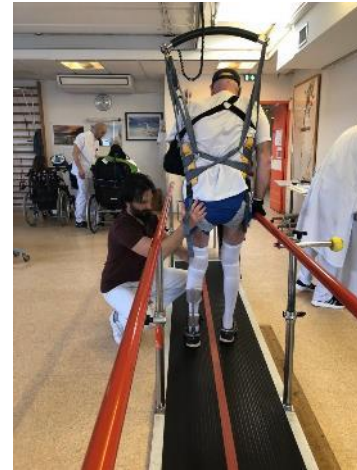


Figure 24 Source: <https://carnotstar.univ-amu.fr/fr/actualites/promouvoir-la-silver-economy-et-contribuer-la-recherche-sur-le-handicap> (accessed 02/06/2022)

A.2.2.e Robotic arm for powered wheelchair

The Kinova® Jaco®⁵⁷ assistive robotic arm controlled with joystick is used at LAMIH to improve the ergonomic quality of powered wheelchairs.



Figure 25 JACO® Robotic arm. Source <https://assistive.kinovarobotics.com/product/jaco-robotic-arm> (accessed 02/06/2022)

⁵⁵ <https://www.uphf.fr/LAMIH/en/development-specialised-exoskeleton-rehabilitation-severe-hemiplegic-patient-order-recover> (accessed 02/06/2022)

⁵⁶ <http://www.primoh.fr/projet-rehabbyexo-projet-de-recherche-qui-vise-developper-un-exosquelette-pour-la-reeducation-du> (id.)

⁵⁷ <https://assistive.kinovarobotics.com/product/jaco-robotic-arm> (id.)

A.2.2.f Embedded system to prevent fall risk

The goal of the **SERICH** project⁵⁸ is to design a technological solution to **prevent and reduce the risk of fall**, based on various expertise such as embedded system, automatic control or biomechanics). SERICH was an opportunity for creating a startup⁵⁹.



Figure 26 Source : <https://medi-wat.com> (accessed 03/05/2022)

A.2.2.g Assistance tool for the mobility of young people with disabilities in the Valenciennes conurbation

The **ValMobile** project⁶⁰ aims to develop an application dedicated to the **mobility of young people (aged 13–30 years) in the Valenciennes conurbation**. The approach is truly users-centred (see Lakehal, 2019⁶¹).

•Aymen Lakehal, Sophie Lepreux, Christos Efstratiou, Christophe Kolski, Pavlos Nicolaou (2020). Investigating smartphones and AR glasses for pedestrian navigation and their effects in spatial knowledge acquisition. In: *Proceedings of the 22nd International Conference on Human-Computer Interaction with Mobile Devices and Services, MobileHCI'20 Extended Abstracts*. <https://doi.org/10.1145/3406324.3410722>

•Laurie Letalle, Aymen Lakehal, Hursula Mengue-Topio, Johann Saint-Mars, Christophe Kolski, Sophie Lepreux, Françoise Anceaux (2020). Ontology for mobility of people with intellectual disability: Building a basis of definitions for the development of navigation aid systems. In: Krömker H. (eds), *HCI in Mobility, Transport, and Automotive Systems. Automated Driving and In-Vehicle Experience Design. HCII 2020, Lecture Notes in Computer Science*, vol. 12212. https://doi.org/10.1007/978-3-030-50523-3_23

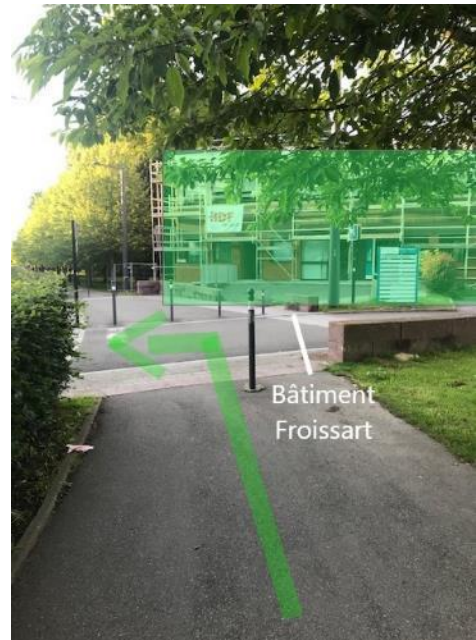


Figure 27 Augmented reality in the ValMobile project. Source: Lakehal, 2019

⁵⁸ <https://www.univ-valenciennes.fr/LAMIH/en/embedded-system-personalization-risk-fall-prm> (accessed 02/06/2022)

⁵⁹ <https://medi-wat.com> (id.)

⁶⁰ <https://www.uphf.fr/LAMIH/en/valmobile> (id.)

⁶¹ Aymen Lakehal (2019). Contribution à la conception centrée utilisateur et à l'évaluation d'un système interactif aidant la mobilité de personnes en situation de déficience intellectuelle. 31e conférence sur l'Interaction Homme-Machine IHM'19. http://iihm.imag.fr/IHM19/IHM-2019/C_ResumesEtendus/1_RencontresDoctorales/dc08-lakehal.pdf (id.)

A.2.2.h Assistance tool for the mobility of people with intellectual disabilities

The **SAMDI** project⁶² has two goals : (i) to develop a tool dedicated to the **mobility of people with intellectual disabilities**, adapting to fit with the user and the environment; (ii) to develop and structure collaborations between universities and academic disciplines (e.g., human & social sciences and science & technology), as well as between the voluntary sector and entrepreneurship.

A.2.2.i Application dedicated to the mobility of the elderly people

PartEnS⁶³ is a ‘Chercheurs-Citoyens’ project funded by Région Hauts-de-France. The goal is to promote aging well through the design of a socio-computer tool that facilitates meetings between isolated seniors who share compatible goals in terms of holidays.

- Gérald Delelis, Janick Naveteur, Pascal Antoine, Yann Secq (2017). « Partir Ensemble Séniors » (PartEnS) : une plate-forme de repérage d’affinités et d’appariement pour promouvoir les vacances des séniors. In : *Actes du 10ème Congrès International de Psychologie Sociale Appliquée (CIPSA)*. <https://lilloa.univ-lille.fr/handle/20.500.12210/58064>
- Janick Naveteur, Pascal Antoine, Yann Secq, Emmanuelle Adam, Gérald Delelis, Maxime Morge, Emmanuelle Grislin-Le Strugeon, Antoine Nongaillard (2018). Partir Ensemble Séniors (PartEnS) : un projet interdisciplinaire centré utilisateur pour des vacances partagées. In : *Actes de ERGO’IA 2018. Conception et usages : comment réussir l’intégration pluridisciplinaire dans la conception centrée utilisateur, et pour quelles retombées ?* <https://hal.archives-ouvertes.fr/hal-01882593/document>.

⁶² <https://www.uphf.fr/LAMIH/en/mobility-aid-system-people-intellectual-disabilities> (accessed 02/06/2022)

⁶³ <https://www.uphf.fr/LAMIH/en/partners-search-engine-help-seniors-go-holidays-together> (id.)

A.3 Interactive tabletop

An interactive tabletop is a large computer interface (large enough to allow several users to interact simultaneously), the users' inputs being the position of their fingers or of dedicated objects (see Dillenbourg & Evans, 2011⁶⁴). Kubicki et al. (2012)⁶⁵ distinguished: tactile interface

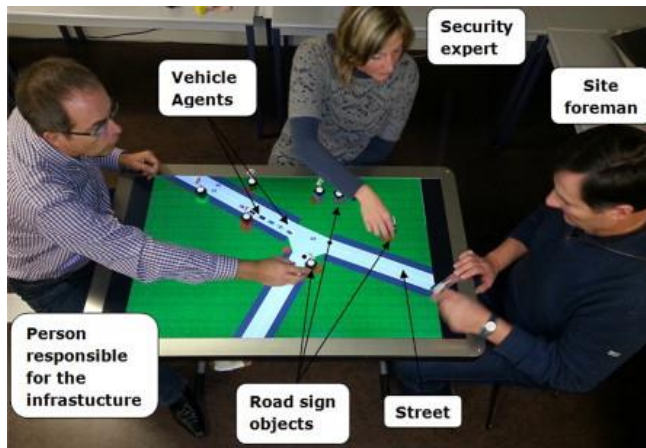


Figure 28 A road traffic simulation on an interactive tabletop.
Source: Lebrun et al., 2015, p. 592

allowing interaction with virtual objects, tangible interface allowing interaction with tangible objects, and mixed interface. This variety of interactions enables researchers to use interactive tabletops in many fields including health and transportation. For example, LAMIH used a RFID interactive tabletop in a study related to the management of a road traffic simulation (Lebrun et al., 2015). Another example:

distributed tangible tabletops were used in a study that examined tabletop-based communication between patients with Alzheimer's disease and a healthcare center (Merrad et al., 2020).

- Yoann Lebrun, Emmanuel Adam, René Mandiau, Christophe Kolski (2015). A model for managing interactions between tangible and virtual agents on an RFID interactive tabletop: Case study in traffic simulation. *Journal of Computer and System Sciences*.
<https://doi.org/10.1016/j.jcss.2014.11.011>

- Walid Merrad, Alexis Héloir, Christophe Kolski, Gloria Mark, Antonio Krüger (2020). Towards monitoring patients with Alzheimer's disease activity using distributed tangible tabletops and dual reality. In: *Proceedings of the 2020 IEEE 33rd International Symposium on Computer-Based Medical Systems (CBMS)*.
<https://doi.org/10.1109/CBMS49503.2020.00034>

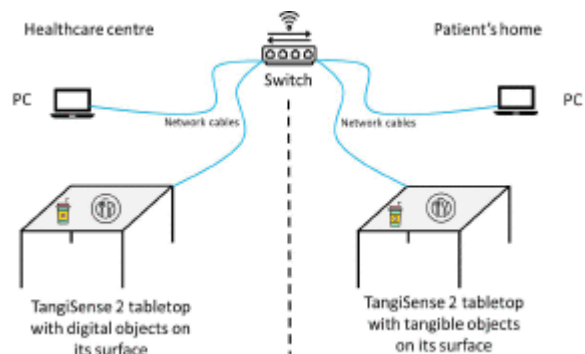


Figure 29 Scheme of the software application for communication with one patient. Source: Merrad et al., 2020, p. 144

⁶⁴ Dillenbourg P., Evans M. (2011). Interactive tabletops in education. *International Journal of Computer-Supported Collaborative Learning*. <https://doi.org/10.1007/s11412-011-9127-7>

⁶⁵ Kubicki S., Borgiel K., Lepreux S., Wolff M., Kolski C. (2012). Réflexions autour des tables interactives : expérience utilisateur, utilisabilité, évaluation [Reflections on Interactive Tabletops: User Experience, Usability, Evaluation]. *Le travail humain*. <https://doi.org/10.3917/th.753.0229>

A.4 Virtual reality, augmented reality and mixed reality

A few words about virtual reality end this section on platforms, technologies and projects. Indeed, using simulators often implies using virtual reality, and a human-centred approach involves considering the user in the design of cognitive and sensorimotor interactions with the virtual environment. This chapter is mainly documented by the French Association for Virtual Reality and Mixed Reality through the book edited by Fuchs, Moreau and Guitton (2011)⁶⁶, other references are specified in footnotes.

A.4.1 Definitions

A.4.1.a Virtual reality

Virtual reality (VR) is “a scientific and technical domain that uses computer science and behavioural interfaces to simulate in a virtual world the behaviour of 3D entities, which interact in real time with each other and with one or more users in the most effective pseudo-natural immersion via sensorimotor channels” (p. 8): the purpose of VR is to make possible that a person perceives and acts (i.e., cognitive and sensorimotor activity) in a digitally created artificial world. The human senses are: i/ exteroceptive senses (sight, taste, smell, etc.) and ii/ somaesthesia including proprioception (i.e., position of the body in relation to the external environment), kinaesthesia (i.e., movement of the body and its limbs in relation to the environment), and interoception (internal state of the body); in VR, the haptic sense includes the sense of touch and muscular-tendinous proprioception (Fuchs, 2018⁶⁷, Chapter 2).

Behavioural interfaces (Figure 32) are material interfaces that enable users to transpose the perception, cognition and action loop of their behaviour in a real world onto interactive virtual environment: motor interfaces capture their actions (gesture, movements, voice, etc.); sensory interfaces enable them to perceive the consequences of their action on the virtual environment; sensorimotor interfaces work in both directions.

Immersion and interaction are the two key conditions of VR, they must be achieved, even in a modest way, to enable us to say that a system is based on VR techniques.

⁶⁶ Fuchs P., Moreau G., Guitton P. (eds) (2011). Virtual reality: Concepts and technologies. Boca Raton, FL: CRC Press

⁶⁷ Fuchs P. (2018). Théorie de la réalité virtuelle. Les véritables usages. Paris : Presses des Mines - Transvalor

- **Real-time** interaction with virtual environment means that the user does not perceive latency between his/her action on the environment and its sensorial response;
- **Immersion** is said to be pseudo-natural because it cannot be natural, we have learnt to act naturally in the real world⁶⁸. Immersion is not only visual, it can also be audio, proprioceptive or cognitive immersion. The subjective aspect of immersion refers to the sensation – i.e., that refers “to the general feeling or impression caused par a particular experience⁶⁹” – of being enveloped by or immersed in the virtual environment; the consequence of perceived immersion is the feeling of **presence** in the virtual environment, i.e., of ‘being there,’ as being a part of the environment (Weitmer et al., 2005⁷⁰). Notice that there are other definitions of immersion and presence, see Nilsson et al., 2016⁷¹. Sensation, feeling, etc. are concepts referring to a person’s perceptions, they are specific to this person, they do exist for her and are thus known by us only if she shares them to us: perceived immersion and perceived presence can be assessed by means that enable the person to express her mental experience, for example, questionnaires.

A.4.1.b Augmented reality

Augmented reality (AR) is “a technology that **superimposes a computer-generated image on a user’s view of the real world**, thus providing a composite view. [...] an enhanced version of reality [...]” (McMillan et al., 2017⁷², p. 163).

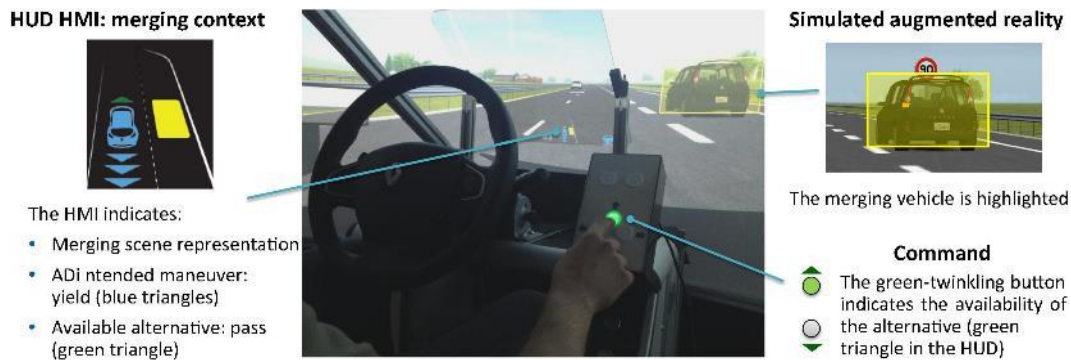


Figure 30 Example of augmented-reality head-up display on the LRA - SystemX Dr SiHMI platform. Source: Guo et al. (2019). <https://doi.org/10.1016/j.trf.2017.04.006>

⁶⁸ https://gdt.oqlf.gouv.qc.ca/ficheOqlf.aspx?Id_Fiche=26529598 (accessed 08/06/2022)

⁶⁹ <https://www.collinsdictionary.com/dictionary/english/sensation> (accessed 07/06/2022)

⁷⁰ Witmer B. G., Jerome C. J., Singer M. J. (2005). The factor structure of the presence questionnaire. *Presence: Teleoperators & Virtual Environments*. <https://doi.org/10.1162/105474605323384654>

⁷¹ Nilsson N.C., Nordham R., Serafin S. (2016). Immersion revisited: A review of existing definitions of immersion and their relation to different theories of presence. *Human Technology*. <https://doi.org/10.17011/ht/urn.201611174652>

⁷² McMillan K., Flood K., Glaeser R. (2017). Virtual reality, augmented reality, mixed reality, and the marine conservation movement. *Aquatic Conservation: Marine and Freshwater Ecosystems*. <https://doi.org/10.1002/aqc.2820>

A.5.1.c Mixed reality

Mixed/merged reality is “the merging of real and virtual worlds to produce new environments and visualizations where physical and digital objects co-exist and interact in real time” (Mc Millan et al.⁷², p. 163).



Figure 31 Mont-Saint-Michel and mixed reality. Source: <https://inculture.microsoft.com/arts/le-mont-saint-michel-mixed-reality/> (accessed 09/06/2022)

A.5.2 Behavioural interfaces

Behavioural interfaces enables users to interact with the VR environment; they are **physical interfaces that enable users to transpose the perception, cognition and action loop of their behaviour in a real world onto interactive virtual environment.**

- motor interfaces capture their actions (gesture, movements, voice, etc.);
- sensory interfaces enable them to perceive the consequences of their action on the virtual environment;
- sensorimotor interfaces work in both directions.

Figure 32 is a non-exhaustive panorama of behavioural interfaces; information comes from Fuchs et al. (2011)⁶⁶, Fuchs (2018)⁶⁷, and Burkhardt and Coquillart (2006)⁷³.

⁷³ Burkhardt J.-M., Coquillart S. (coord) (2006). *Le traité de la réalité virtuelle. Volume 2. L'interfaçage, l'immersion et l'interaction en environnement virtuel*. Paris : École des Mines de Paris

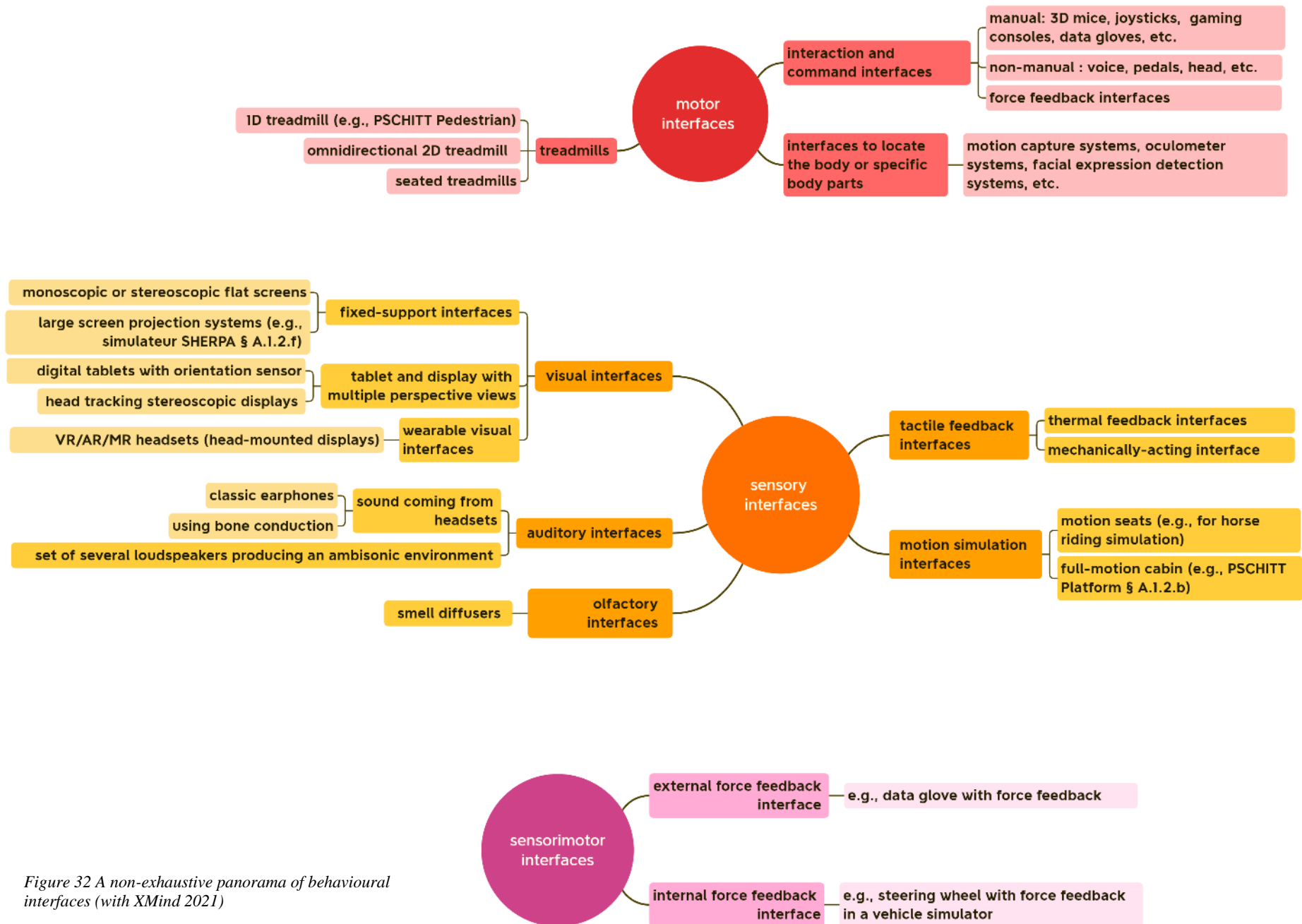


Figure 32 A non-exhaustive panorama of behavioural interfaces (with XMind 2021)

Some references from LAMIH about works using virtual reality:

- Hault-Dubrulle Audrey, Robache Frédéric, Pacaux Marie-Pierre, Morvan Hervé. (2011). Determination of pre-impact occupant postures and analysis of consequences on injury outcome. Part I: A driving simulator study. *Accident Analysis & Prevention*.
<https://doi.org/10.1016/j.aap.2010.07.012>
- Mohammed Elsaeh, Philippe Pudlo, Mohamed Djemai, Mohamed Bouri, André Thevenon, Isabelle Heymann (2017). The effects of haptic-virtual reality game therapy on brain-motor coordination for children with hemiplegia: A pilot study. In: *Proceedings of the 2017 International Conference on Virtual Rehabilitation (ICVR)*. <https://doi.org/10.1109/ICVR.2017.8007472>
- Benloucif Mohamed Amir, Sentouh Chouki, Floris Jérôme, Simon Philippe, Boverie Serge, Popieul J.-C. (2016). Cooperation between the driver and an automated driving system taking into account the driver's state. *Driving Simulation & Virtual Reality Conference & Exhibition DSC 2016 Europe^{VR}*.
<https://hal-uphf.archives-ouvertes.fr/hal-03417156>
- Azzedine Aissaoui, Abdelkrim Ouafi, Philippe Pudlo, Christophe Gillet, Zine-Eddine Baarir, Abdlemalik Taleb-Ahmed (2018). Designing a camera placement assistance system for human motion capture based on a guided genetic algorithm. *Virtual Reality*. <https://doi.org/10.1007/s10055-017-0310-7>
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<https://doi.org/10.1109/SMC.2019.8913960>
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Human-Centred Research & Design for Inclusive Mobility.

Section B – Human-Centred Approaches

Section B presents two human-centred approaches that can be applied to research on and design of mobility-related technologies, but not only.

B.1 Some general remarks

The approach of human-centred engineering and industrial design considers that the finality of technology is humans, in their individuality as well as their sociality (Figure 33), but also as an entity among others within nature in the era of Industry 5.0 (Figure 34).

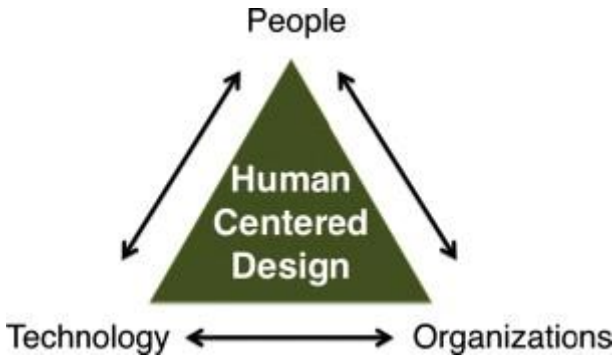


Figure 33 A human-centred perspective on engineering and industrial design. Source: Boy G.A. (2014). From automation to tangible interactive objects. *Annual Reviews in Control*. <https://doi.org/10.1016/j.arcontrol.2014.03.001>

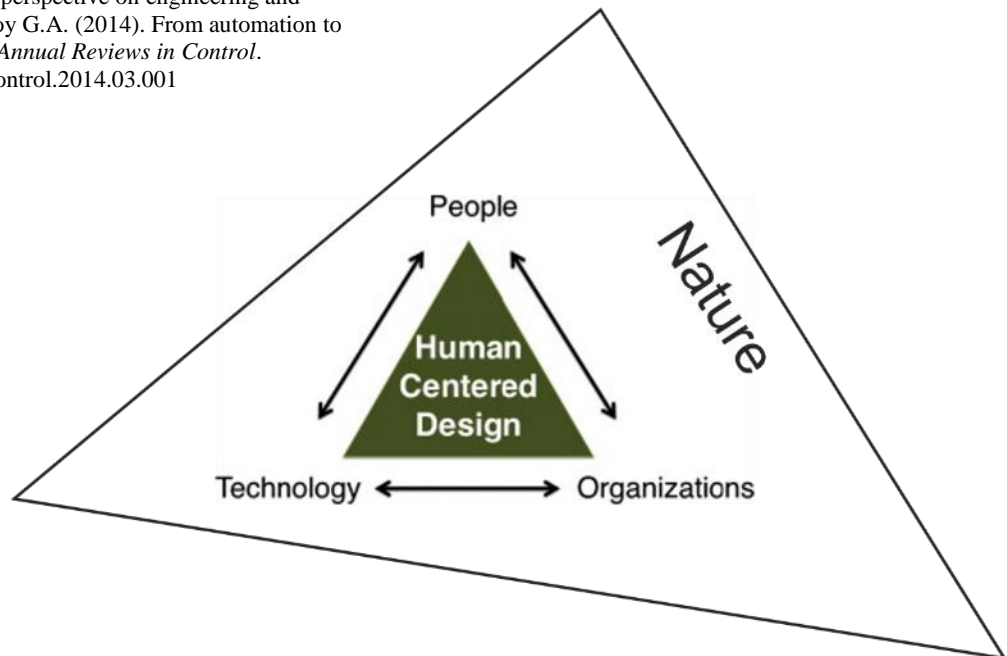


Figure 34 Guy Boy's TOP-model inserted into a wider human environment, i.e., nature



Figure 35 Figure HMS... Source : pixabay.com

This document considers two human-centred research & design approaches : i/ [an approach centred on human factors](#), which is relevant to human-machine systems (HMS) – i.e., human-machine interaction and human-machine cooperation (a particular form of interaction implying autonomous agents interacting in dynamic

situations and who can share functions) – in dynamic situations (i.e., that evolve independently of human intervention)^{74,75} ii/ [an approach centred on users](#), originally applied to human-computer interaction⁷⁶ (HCI). HCI refers here to both interaction and interface, even though they do not have the same meaning, users interacting with technologies through interfaces⁷⁷.



Figure 36... and HCI. Source: pixabay.com

The human factors and users-centred approaches are [opposed to the techno-centred design approach](#); for both, the human (operators, users) must be integrated from the beginning of the design process of the technology or of the interaction through the process of identification of their real needs, as well along the design process through evaluations^{78,79} In a word, the ultimate goal of anthropocentric approaches is [to design technologies and services that adapt to users' needs and abilities](#). This gets more complex in socio-cyber-physical systems (e.g., Figure 37, the hospital environment): researchers and engineers also have to deal with the organisational environment (legal statuses, relationships between people, between services, logistics, etc.) and the societal environment (health protection systems, political context, social norms, etc.) (Figure 33, Figure 38), but also with nature (Figure 34) (systematic application of principles of green computing, energy efficiency or sustainable logistics, etc.).

⁷⁴ Hoc J.-M. (2001). Towards a cognitive approach to human-machine cooperation in dynamic situations. *International Journal of Human-Computer Studies*. <https://doi.org/10.1006/ijhc.2000.0454>

⁷⁵ Hoc J.-M. (2000). From human-machine interaction to human-machine cooperation. *Ergonomics*. <https://doi.org/10.1080/001401300409044>

⁷⁶ Norman D.A., Draper S.W. (eds) (1986). *User centred system design. New perspectives on human-computer interaction*. Hillsdale, NJ: Lawrence Erlbaum Associates

⁷⁷ Beaudouin-Lafon M. (2004). Designing interaction, not interfaces. *Proceedings of the Working Conference on Advanced Visual Interfaces AVI'04*. <https://doi.org/10.1145/989863.989865>

⁷⁸ Trentesaux D., Millot P. (2016). A human-centred design to break the myth of the “magic human” in intelligent manufacturing systems. In: Borangiu T., Trentesaux D., Thomas A., McFarlane D. (eds), *Service orientation in holonic and multi-agent manufacturing*. Studies in Computational Intelligence. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-30337-6_10

⁷⁹ Lepreux S., Abed M. Kolski C. (2003). A human-centred methodology applied to decision support system design and evaluation in a railway network context. *Cognition, Technology & Work*. <https://doi.org/10.1007/s10111-003-0128-9>

A « human-centred » project generally emanates from and a societal demand that is latent or expressed by specific populations, e.g., elderly pedestrians, handicapped young adults, train drivers. This implies that the first principle of a human-centred design approach is to carry out a **needs analysis**: researchers meet users and other stakeholders in order to identify their real needs, preferences and constraints. Techniques for needs analysis will be described in *Section C - Methods and Techniques*.

This is an example of human-centred project: the **ParkinsonCom European Interreg France-Wallonie-Vlaanderen** Project⁸⁰ is dedicated to the design of a communication support for people with Parkinson's disease. The end users are the patients, their relatives, and the medical staff who communicates with them; but the Parkinson disease, like other many diseases, is a societal challenge for society and researchers. Therefore, stakeholders participate to the project besides UPHF and LAMIH, Université de Mons, Universitair Ziekenhuis Brussel: Centre Hospitalier Universitaire de Lille, Association France Parkinson (both committees of Nord and Pas-de-Calais), Association Parkinson asbl⁸¹, Vlaamse Parkinson Liga⁸², and Drag On Slide SRL (Mons, Belgique).

In other projects of the MH2 Axis¹¹, the French **Fondation HOPALE** is a constant partner (e.g., **GRAAL**⁵³, **STRAAL**⁵⁴).

The other principle of human-centred design approaches is the iterative development process: repeated evaluations of usability, effects of human factors on human-machine system's performance, user's satisfaction, stakeholders' contentment, etc. are part of the design process in addition to technical tests. The goal is to **ensure that objectives set after the needs analysis process are met**.



Figure 39
Source :<http://www.fondation-hopale.org/>

⁸⁰ <https://www.uphf.fr/LAMIH/en/communication-support-software-better-social-inclusion-people-parkinsons-disease> (accessed 13/06/2022)

⁸¹ <https://www.parkinsonasbl.be/accueil/mentions-legales/> (accessed 13/06/2022)

⁸² <https://www.parkinsonliga.be> (id)

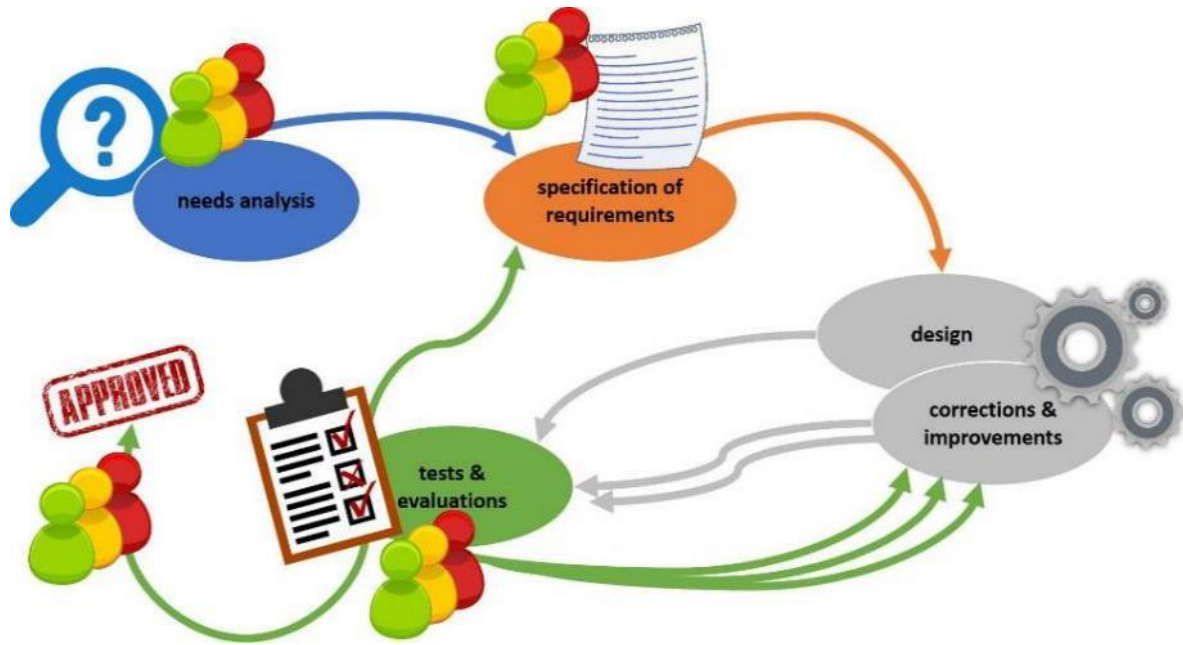


Figure 40 Human-centred design approaches: the human (users, operators, stakeholders) is almost at all levels of the design process (pictures from pixabay.com)

B.2 Research & design centred on human factors

B.2.1 Definitions

As early as 1958, Morehouse advocated a philosophy of human factors crossing engineering and life science to better understand the human-machine-environment relationship and, ultimately, ensure “the optimal utilization of human and machine capabilities to achieve the highest degree of effectiveness of the total system” (Morehouse, 1958⁸³, p. 1).

“The definition of ergonomics (or human factors) adopted by the IEA in 2000 is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimise human well-being and overall system performance” (International Ergonomics Association⁸⁴).

The present document does not deal with classical ergonomics, it only considers cognitive ergonomics (“it’s all in the mind,” Hollnagel, 1997⁸⁵): and as such, **a human factor is considered**

⁸³ Morehouse L.E. (1958). A human factors philosophy. *Human Factors*. <https://doi.org/10.1177/001872085800100101>

⁸⁴ International Ergonomics Association: <https://iea.cc/what-is-ergonomics/> (accessed 14/06/2022)

⁸⁵ Hollnagel E. (1997). Cognitive ergonomics: it’s all in the mind. *Ergonomics*. <https://doi.org/10.1080/001401397187685>

as an “internal” variable that characterises the human operator/user in dynamic situations in which the human can exert only partial control⁸⁶ (e.g., car driving) and could explain his/her behaviour and/or the overall performance of the human-machine system. For example, a researcher will analyse the effect of vigilance on the driver’s capacity to detect and avoid a zebu that crosses the road; or he/she will analyse the effect of the level of autonomy of a social robot on the quality of the interaction between the robot and an elderly at home or on his/her well-being.

B.2.2 Examples of human factors

Table 1 presents the most studied human factors, the list being far from exhaustive. References are provided for the student interested to get more knowledge, for example:

Kahneman D. (2011). *Thinking, fast and slow*. NY: Farrar, Straus and Giroux.

Salvendy G. and Karwowski W. (eds) (2021). *Handbook of human factors and ergonomics* 5th edition. Hoboken, NJ: John Wiley & Sons.

Carayon P. (ed) (2016). *Handbook of human factors and ergonomics in healthcare and patient safety* Second edition. Boca Raton, FL: CRC Press (not cited in Table 1).

⁸⁶ Hoc J.-M., Amalberti R. (2007). Cognitive control dynamics for reaching a satisficing performance in complex dynamic situations. *Journal of Cognitive Engineering and Decision Making*. <https://doi.org/10.1177/155534340700100102>

Table 1 A brief panorama of human factors for the studies of human-machine systems (per alphabetical order)

Human factors	Definitions	References
<p>Acceptability Acceptance Social acceptability ** the tool – e.g., items of a questionnaire – that will measure the acceptability and/or acceptance related to “your” system will depend on the definition you choose</p>	<ul style="list-style-type: none"> - Acceptability is a prospective judgement of measures (or systems) to be introduced in the future (Shade & Schlag, 2003⁸⁷); <i>a priori</i> acceptability (Pianelli et al., 2007⁸⁸) - Acceptance defines attitudes including behavioral reactions after the introduction of the measure (Shade & Schlag, 2003); <i>a posteriori</i> acceptability (Pianelli et al., 2007) - Acceptance is the degree to which an individual intends to use a system and, when available, to incorporate the system in his/her driving (Adell et al., 2014) - The overall acceptability of a system is the combination of its social acceptability (that relies on social factors such as social desirability) and its practical acceptability (that relies on attributes such as usefulness, reliability and cost (Nielsen, 1993⁸⁹)) 	<p>Adell E., Várhelyi A., Nilsson L. (2014). The Definition of acceptance and acceptability. In: M. A. Reagan, T. Horberry, A. Stevens (eds), <i>Driver Acceptance of New Technology</i> (Chapter 2). Boca Raton, FL: CRC Press.</p> <p>Venkatesh V., Morris M. G., Davis G. B., Davis F. D. (2003). User acceptance of information technology: Toward a unified view. <i>MIS Quarterly</i>, 27(3), 425-478.</p>
<p>Attention (See also ‘cognitive load’)</p>	<p>Attention often refers to the ability to select some aspect of incoming stimulation for further analysis⁹⁰; it is also defined as “a state in which cognitive resources are focused on certain aspects of the environment rather than on others and the central nervous system is in a state of readiness to respond to stimuli.”⁹¹</p> <p>It is hypothesised that attentional resources are limited (e.g., Kahneman, 1973)</p> <p>Voluntary attention (paying attention) requires conscious and directed mental effort, it is produced by ‘system 2’, one of the two ways of thinking according to Kahneman (2011)</p>	<p>Kahneman D. (1973). <i>Attention and effort</i>. London: Prentice Hall</p> <p>Kahneman D. (2011). <i>Thinking, fast and slow</i>. NY: Farrar, Straus and Giroux</p>

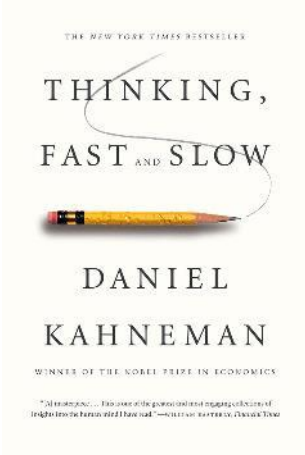
⁸⁷ Schade J., & Schlag B. (2003). Acceptability of urban transport pricing strategies. *Transportation Research Part F*. [https://doi.org/10.1016/S1369-8478\(02\)00046-3](https://doi.org/10.1016/S1369-8478(02)00046-3)

⁸⁸ Pianelli C., Saad F., Abric J-C. 2007. Social representations and acceptability of LAVIA (French ISA system). *Proceedings of the 14th World Congress on ITS*, 9-13 October 2007, Beijing, Peoples' Republic of China

⁸⁹ Nielsen J. (1993). *Usability engineering*. Mountain View, CA: AP Professional

⁹⁰ Eysenck M.W. (2001). *Principles of cognitive psychology* 2nd edition. Hove, UK: Psychology Press Ltd

⁹¹ <https://dictionary.apa.org/attention>

	<p>Selective (or directed) attention : concentration on certain stimuli in the environment and not on others, enabling important stimuli to be distinguished from peripheral or incidental ones.⁹²</p> <p>Divided attention: attention to two or more channels of information at the same time, s that two or more tasks may be performed concurrently.⁹³</p>	
<p>Automatisms and controlled processes</p> <p>See also: (Cognitive control; Cognitive load)</p>	<p>Schiffrin & Schneider (1984) consider that information processes are controlled at two levels:</p> <ul style="list-style-type: none"> - Controlled processing requiring attentional effort - Automatic processing running with little or no attentional effort <p>Automatisms are nonpurposeful behaviour performed mechanically, without intention and without conscious awareness⁹⁴ would be produced by the ‘system 1’, while controlled operations would be related to effortful mental activities of the ‘system 2’</p> <p>“All learning starts from a way of working that is based on knowledge and ends with a way of working that is based on habits and routines. What characterises an expert is the increased availability of these routines, allowing him to work more quickly and cope with a larger workload” (Amalberti, 2013)⁹⁵</p>	 <p>The image shows the front cover of the book 'Thinking, Fast and Slow' by Daniel Kahneman. The cover is white with black text. At the top, it says 'THE NEW YORK TIMES BESTSELLER'. The title 'THINKING, FAST AND SLOW' is written in a large, serif font, with a yellow pencil drawing a line through the word 'AND'. Below the title is the author's name 'DANIEL KAHNEMAN' in a smaller, bold, serif font. At the bottom, it says 'WINNER OF THE NOBEL PRIZE IN ECONOMICS'. There is also a small quote at the very bottom.</p> <p>Figure 41. Source: https://us.macmillan.com/books/9780374533557/thinkingfastandslow (accessed 15/06/2022)</p> <p>Schiffrin R.M., Schneider W. (1984). Automatic and controlled processing revisited. <i>Psychological Review</i>, 91(2), 269-276</p>
<p>Biases and heuristics</p>	<p>A cognitive heuristic is an adaptive mental strategy, a shortcut that facilitates judgement and decision processes in making sense of the world, with small effort and time costs; a bias is often considered in comparison with normative, rational reasoning⁹⁶</p> <p>Availability heuristic: the frequency or probability of an event is judged by the number of instances of it that can easily be brought in mind: can generate biased judgements⁹⁷</p>	<p>Kahneman D. (2011). <i>Thinking, fast and slow</i>. NY: Farrar, Straus and Giroux</p>

⁹² <https://dictionary.apa.org/selective-attention> (accessed 15/06/2022)

⁹³ <https://dictionary.apa.org/divided-attention> (id.)

⁹⁴ <https://dictionary.apa.org/automatism> (id.)

⁹⁵ Amalberti R. (2013). *Navigating safety. Necessary compromises and trade-offs - Theory and practice*. Dordrecht, Netherlands: Springer

⁹⁶ Gigerenzer G., Brighton H. (2009). Homo heuristics: Why biased minds make better inferences. *Topics in Cognitive Science*. <https://doi.org/10.1111/j.1756-8765.2008.01006.x>

⁹⁷ Colman A.M. (2015). *A dictionary of psychology* 4 ed. Oxford, UK: Oxford University Press

	<p><u>Representativeness heuristic</u>: people estimate the probability that <i>A</i> belongs to a particular class <i>B</i> by judging the degree to which <i>A</i> is representative of <i>B</i>; can lead to errors of judgment⁹⁷</p> <p><u>Confirmation bias</u>: the tendency to favour paying attention to information that confirms existing hypotheses or beliefs⁹⁸</p> <p><u>Affect heuristic</u>: the judgement is influenced by the affect associated with the object of judgement.⁹⁹</p>	
<p>Cognitive (or mental) load Cognitive resources See also: Attention</p>	<p>An operational definition of cognitive load is “the operator’s allocation of limited processing capacity or resources to meet task demands; that is, the balance of internal resources and external demands”¹⁰⁰, the ratio between the demands of the task and the available human cognitive resources (Cegarra & Chevalier, 2008).</p> <p>There is a notion of mental effort behind the concept of cognitive load¹⁰¹ (comparable with the notion of physical effort)</p> <p>There is a relationship between cognitive load and cognitive resources, but they should not be confused. Cognitive resources are related to attentional resources in the sense that attention is the flexible allocation of cognitive resources¹⁰². They are limited but they are multiple, distributed depending on: the nature of the task or the task component; mobilised perceptive channels (visual, auditory); whether the task could be done in parallel; etc. See the model of multiple resources and mental workload of Wickens (2008).</p> <p>Cognitive load should not be confused with workload: workload involves considering the degree of cognitive, physical and psychological mobilisation of the individual with regard to related constraints such as goals, expected results and expected quality¹⁰³</p>	<p>Cegarra J., Chevalier A. (2008). The use of Tholos software for combining measures of mental workload: Toward theoretical and methodological improvements. <i>Behavior Research Methods</i>. https://doi.org/10.3758/BRM.40.4.988</p> <p>Hancock G.M., Longo L. Young M.S., Hancock P.A. (2021). Mental workload. In: G. Salvendy and W. Karwowski (eds) (2021). <i>Handbook of human factors and ergonomics</i> 5th edition (Chapter 7, pp. 203-226). Hoboken, NJ: John Wiley & Sons</p> <p>Wickens C. D. (2008). Multiple resources and mental workload. <i>Human Factors</i>. https://doi.org/10.1518%2F001872008X288394</p>

⁹⁸ Breakwell G.M. (2014). *The psychology of risk*. Cambridge, UK: Cambridge University Press

⁹⁹ Finucane M. L., Alhakami A., Slovic P., Johnson S. M. (2000). The affect heuristic in judgments of risks and benefits. *Journal of Behavioral Decision Making*, 13(1), 1-17

¹⁰⁰ Matthews G, Reinerman-Jones (2017), cited by Hancock et al. (2021)

¹⁰¹ Tricot A., & Chanquoy L. (1996). Introduction : la charge mentale, " vertu dormitive" ou concept opérationnel ? [Mental workload: a ‘sleep-inducing virtue or an operational concept?'] *Psychologie Française*, 41(4), 313-318.

¹⁰² Dosenbach N.U.F. and Petersen S.E. (2009). Attentional networks. *Encyclopedia of Neuroscience*. <https://doi.org/10.1016/B978-008045046-9.00204-7>

¹⁰³ Falzon P., Sauvagnac C. (2004). Charge de travail et stress [Workload and stress]. In : P. Falzon (dir), *Ergonomie* (Chapter 11). Paris : PUF

	Mental workload can be inferred from primary and secondary task performance measures, subjective measures (questionnaires), physiological measures (see Hancock et al., 2021)	
Cognitive compromise	Dynamic adjustment of cognitive resources to achieve/maintain a satisfactory level of performance	Amalberti R. (2013). <i>Navigating safety. Necessary compromises and trade-offs - Theory and practice</i> . Dordrecht, Netherlands: Springer
Cognitive control of mental activities	<p>The SRK model of Rasmussen (1976, 1983) considers three levels of performance based on three types of behaviour and corresponding levels of abstraction of control (e.g., the more elaborate the mental activity, the more symbolic the control):</p> <ul style="list-style-type: none"> - skill-based behaviour, i.e., sensorimotor performance taking place without conscious control; - rules-based behaviour, i.e., the performance is structured by ‘feedforward control’ through a stored rule. The boundary between ‘skill-based’ and ‘rules-based’ depends on the level of training and the attention of the operator; - knowledge-based behaviour, i.e., performance is goal-controlled and based on knowledge during unfamiliar situations (neither routines nor rules are available), the control of data processing is conscious and resources consuming <p>Starting from the SRK model, Hoc and Amalberti (2007) proposed a model of cognitive control in dynamic situations where the operator can exert only partial control⁷⁴. The model distinguishes symbolic data (symbolic activities) from subsymbolic data (routines) and data in the environment (reactive activities) from data in the mind (anticipative activities). The idea of cognitive compromise relies on this model: the operator adjusts the allocation of cognitive resources to reach a satisficing performance level given the quantity of cognitive resources which can be dedicated to at a given time in a given context for a given goal (that might be adjusted too)</p>	<p>Rasmussen J. (1976). Outlines of a hybrid model of the process plant operator. In: Sheridan T.B., Johanssen G. (eds), <i>Monitoring behavior and supervisory control</i>. NATO Conference Series, Vol. 1 (pp. 371-382). Boston, MA: Springer. https://doi.org/10.1007/978-1-4684-2523-9_31</p> <p>Rasmussen J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. <i>IEEE Transactions on Systems, Man, and Cybernetics</i>. https://doi.org/10.1109/TSMC.1983.6313160</p> <p>Hoc J. M., Amalberti R. (2007). Cognitive control dynamics for reaching a satisficing performance in complex dynamic situations. <i>Journal of Cognitive Engineering and Decision Making</i>. https://doi.org/10.1177%2F155534340700100102</p>
Common frame of reference	The common frame of reference in cognitive cooperation (a particular form of cognitive interaction between two agents ⁷⁵) is an internal model of shared knowledge of both the external situation and agents’ goals and plans (Hoc & Carlier, 2002)	<p>Annebicque D., Debernard S., Poulain T., Crevits I. (2008). AMANDA V3: Toward a common workspace between Air Traffic Controllers. In: <i>Proceedings of the First International Conference on Advances in Computer-Human Interaction</i>. https://doi.org/10.1109/ACHI.2008.47</p> <p>Hoc J.-M, Carlier X. (2002). Role of a common frame of reference in cognitive cooperation: Sharing tasks between agents in Air Traffic</p>

		Control. Cognition, Technology & Work. https://doi.org/10.1007/s101110200003
Emotions, feelings	<p>[1] Damasio A. R. (1999). <i>The feeling of what happens: Body and emotion in the making of consciousness</i>. New York: Houghton Mifflin Harcourt Publishing</p> <p>[2] Damasio, A. (2021). <i>Feeling & knowing: Making minds conscious</i>. New York: Pantheon Books.</p> <p>Emotions are complicated collections of co-occurring and involuntary chemical and neural responses (e.g., smooth muscle contractions, changes in heart rate, breathing hormonal secretions, facial expressions, posture) [1][2]. “All emotions have some kind of regulatory role to play”; notwithstanding the reality that learning and culture alter the expression of emotions and give emotions new meanings, emotions are biologically determined processes, depending on innately set brain devices”; “all emotions use the body as their theatre (internal milieu, visceral, vestibular and musculoskeletal systems” [1]</p> <p>Emotions can be categorised into the six so-called primary emotions (happiness, sadness, fear, anger, surprise, disgust), the so-called secondary or social emotions (e.g., embarrassment, jealousy, guilt, pride), and background emotions (e.g., well-being, malaise, calm, tension) [1]</p> <p>The biological function of emotions is twofold: (i) production of a specific reaction to the inducing situation (e.g., to run away); (ii) regulation of the internal state of the organism such as it can be prepared for the specific reaction (e.g., providing increased blood flow to arteries in the legs so that muscles receive extra oxygen and glucose) [1]</p> <p>Feeling are sensory patterns [1], mental experiences, interactive perceptions [2]. All feelings are conscious [2]</p> <p>Emotions, feeling, consciousness: organisms equipped to sense emotions (i.e., to have feelings) and equipped with consciousness are capable of knowing they have feelings: this enhances the organism’s ability to respond adaptively [1]</p> <p>If we adopt Damasio’s definitions, feelings can be investigated by means of questionnaires, whereas emotions cannot be. Other tools are needed, necessarily in combination, to infer emotions from, for example: facial, vocal, gestural and postural expressions; pupillary activity; cardiac activity; respiratory activity; electro dermal activity; muscle activity.</p>	<p>HIGH REASON Complex, flexible, and customized plans of response are formulated in conscious images and may be executed as behaviour</p> <hr/> <p>CONSCIOUSNESS</p> <hr/> <p>FEELINGS Sensory patterns signaling pain, pleasure, and emotions become images</p> <p>EMOTIONS Complex, stereotyped patterns of response, which include secondary emotions; primary emotions, and background emotions</p> <p>BASE LIFE REGULATIONS Relatively simple, stereotyped patterns of response, which include metabolic regulation, reflexes, the biological machinery behind what will become pain and pleasure, drives and motivations</p> <p><i>Figure 42 Levels of life regulations, from Damasio (1999) [1]</i></p>

Human error	<p>Reason (1990) proposed three working definitions:</p> <ul style="list-style-type: none"> - “Error will be taken as a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency” - “Slips and lapses are errors which result from some failure in the execution and/or storage of an action sequence, regardless of whether or not the plan which guided them was adequate to achieve its objective” - “Mistakes may be defined as deficiencies or failures in the judgemental and/or inferential processes involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not actions directed by this decision-scheme run accordingly to plan.” <p>Reason (1990) proposed to categorise error types following the SRK model of Rasmussen (1983):</p> <ul style="list-style-type: none"> - Skill-based level of slips and lapses: due to inattention (e.g., perceptual confusions, omissions following interruptions) or to overattention (e.g., repetitions, reversals); - Rule-based mistakes: due to the misapplication of good rules or to the application of bad rules; - Knowledge-based mistakes: due to confirmation bias, overconfidence, illusory correlation, problems with causality, problems with complexity, etc. 	<p>Reason J. (1990). <i>Human error</i> (First published, 20th printing 2009). New York: Cambridge University Press</p> <p>Rasmussen J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. <i>IEEE Transactions on Systems, Man, and Cybernetics</i>. https://doi.org/10.1109/TSMC.1983.6313160</p>
Human reliability	<p>Human reliability analysis is concerned with prediction of the likelihood that human performance within a human–machine system will fail¹⁰⁴</p> <p>It is defined as “the probability of accomplishing a task successfully by humans at any required stage in the system operation with a given minimum time limit (if the time requirement is stated)” (Dhillon, 2006)</p>	<p>Dhillon B.S. (2006). <i>Maintainability, maintenance, and reliability for engineers</i>. Boca Raton, FL: CRC Press</p> <p>Liu P., Zhang R., Yin Z., Li Z. (2021). Human errors and human reliability. In: Salvendy G. and Karwowski W. (eds) (2021). <i>Handbook of human factors and ergonomics 5th edition</i> (Chapter 20, pp. 514-572). Hoboken, NJ: John Wiley & Sons</p>
Memory	<p>Memory: “the ability to retain information or a representation of past experience, based on the mental processes of learning or encoding, retention across some interval of time, and retrieval or reactivation of the</p>	<p>Baddeley A. (2010). Working memory. <i>Current Biology</i>. https://doi.org/10.1016/j.cub.2009.12.014</p> <p>Klein S.B (2015). What memory is. <i>WIREs Cognitive Science</i>. https://doi.org/10.1002/wcs.1333</p>

¹⁰⁴ Timpe K.-P, Giesa H.-G., Seifert K. (2004). Engineering Psychology. In: Spielberger C. D., *Encyclopedia of Applied Psychology* (pp. 777-786). Academic Press

	<p>memory”; “he hypothesised part of the brain where traces of information and past experiences are stored”¹⁰⁵</p> <p>Long-term memory: “a relatively permanent information storage system that enables one to retain, retrieve, and make use of skills and knowledge hours, weeks, or even years after they were originally learned”¹⁰⁶</p> <p>Declarative memory: “the ability to retain information about facts or events over a significant period of time and to consciously recall such declarative knowledge, typically in response to a specific request to remember”¹⁰⁷</p> <p>Procedural memory: “long-term memory for the skills involved in particular tasks. Procedural memory is demonstrated by skilled performance and is often separate from the ability to verbalise this knowledge”¹⁰⁸</p> <p>Immediate memory: “a type or stage of memory in which an individual recalls information recently presented, such as a street address or telephone number, although this information may be forgotten after its immediate use. Immediate memory is frequently tested in assessing intelligence or neurological impairment”¹⁰⁹</p> <p>Working memory: refers to the system or systems that are assumed to be necessary in order to keep things in mind while performing complex tasks such as reasoning, comprehension and learning (Baddeley, 2010)</p>	<p>Poos J. M., Jiskoot L. C., Papma J. M., van Swieten J. C., van den Berg E. (2018). Meta-analytic review of memory impairment in behavioral variant frontotemporal dementia. <i>Journal of the International Neuropsychological Society</i>. https://doi.org/10.1017/S1355617718000115</p>
<p>Situation awareness</p>	<p>According to Endsley, situation awareness (SA) for an operator means that he/she knows what is going on around him/her for a given goal at a given time; it is “an internalized mental model of the current state of a person’s environment”</p> <p>SA has three ascending levels that are not linear:</p> <ul style="list-style-type: none"> - Level 1: Perception of the elements of the environment - Level 2: Comprehension of the current situation 	<p>Endsley M. R. (1995). Measurement of situation awareness in dynamic systems. <i>Human Factors</i>. https://doi.org/10.1518/001872095779049499</p> <p>Endsley M. R. et al. (1998). A comparative analysis of SAGAT and SART for evaluations of situation awareness. In: <i>Proceedings of the Human Factors and Ergonomics Society Annual Meeting</i>. https://doi.org/10.1177/154193129804200119</p>

¹⁰⁵ <https://dictionary.apa.org/memory> (accessed 22/06/2022)

¹⁰⁶ <https://dictionary.apa.org/long-term-memory> (id.)

¹⁰⁷ <https://dictionary.apa.org/declarative-memory> (id.)

¹⁰⁸ <https://dictionary.apa.org/procedural-memory> (id.)

¹⁰⁹ <https://dictionary.apa.org/immediate-memory> (id.)

	<ul style="list-style-type: none"> - Level 3: Projection of the future <p>SA can be measured, SAGAT and SART are popular tools:</p> <ul style="list-style-type: none"> - SAGAT (Situation Awareness Global Assessment Technique) requires freezing of simulation scenario; participants are asked to answer queries on relevant SA knowledge on perceptions, comprehension and projection during freeze - SART (Situation Awareness Rating Technique) is based on post-trial subjective opinions assessed with Likert-scale questionnaires about demand on resources (through the complexity of the situation), supply of resources (how cognitive resources are applied), and understanding of the situation 	Endsley M. R. (2021). Situation awareness. In G. Salvendy & W. Karwowski (eds), <i>Handbook of Human Factors and Ergonomics - Fifth edition</i> (Chapter 17, pp. 434-455). Hoboken, NJ: John Wiley & Sons. https://doi.org/10.1002/9781119636113.ch17
Stress and coping	<ul style="list-style-type: none"> •Stress: psychological and physical strain or tension generated by physical, emotional ; social, economic ; or occupational circumstances, events, or experiences that are difficult to manage or endure⁹⁷ •Stress concerns negative person-environment relationships, cognitive appraisals, and emotional response states (Lazarus & Folkman, 1987, an important article) •Coping has two functions: “to change the actual terms of the troubled person-environment relationship” and “to regulate emotional distress” (id.) 	Lazarus R.S., Folkman S. (1987). Transactional theory and research on emotions. <i>European Journal of Personality</i> . https://doi.org/10.1002%2Fper.2410010304
Time perception	<p>Time judgement: the sense of time accounts for the ability to accurately perceive the duration of an event or an interval between two events in a time range from a few hundred milliseconds to several seconds</p> <p>Time pressure: “[...] distinguish between actual time pressure, which refers to objective time constraints, and the feeling of time pressure, where individuals perceive the time available to them to be insufficient. This underscores the importance of measuring both objective time and subjective time in order to detect a lack of time and the feeling of time pressure.”¹¹⁰</p>	<p>Droit-Volet S. (2019). L’ère des temps psychologiques. <i>Journal of Interdisciplinary Methodologies and Issues in Science</i>. https://doi.org/10.18713/JIMIS-160419-7-8</p> <p>Cœugnet S., Naveteur J., Antoine P., Anceaux F. (2013). Time pressure and driving: Work, emotions and risks. <i>Transportation Research Part F</i>. https://doi.org/10.1016/j.trf.2013.05.002</p>
Trust	Trust can be viewed as a tripartite relationship in which A expects B to do/be (Hardin, 2001): trust can be defined in terms of A’s expectations towards B (a human, an institution, a machine, a human-machine system, etc.)	Hardin R. (2001). Conceptions and explanations of trust. In: K.S. Cook (ed), <i>Trust in society</i> (pp. 3-39). New York, NY: Russel Sage Foundation

¹¹⁰ Rattat A. C., Matha P., Cegarra J. (2018). Time flies faster under time pressure. *Acta Psychologica*. <https://doi.org/10.1016/j.actpsy.2018.01.014>

	<p>Notice that OECD has published a guidelines book on measuring trust (OECD, 2017)</p> <p>Automation-induced complacency: operators' overreliance on automation which can be due to overtrust in automation (Parasuraman & Riley, 1997)</p>	<p>https://www.oecd-ilibrary.org/governance/oecd-guidelines-on-measuring-trust_9789264278219-en (accessed 21/06/2022)</p> <p>Lee J. D., Moray N. (1994). Trust, self-confidence, and operators' adaptation to automation. <i>International Journal of Human-Computer Studies</i>. https://doi.org/10.1006/ijhc.1994.1007</p>
Trust in self, self-confidence, self-efficacy	<p>Self-confidence is the “belief or assurance in oneself, trusting one’s abilities, judgments, or decisions”⁹⁷</p> <p>In the study of human-machine systems, trust in automation refers to anticipated performance of automation and trust in self to anticipated performance during manual control (e.g., Lee & Moray, 1994)</p> <p>Self-efficacy is the ability to achieve desired results; perceived self-efficacy includes beliefs about one’s ability or competence to bring about intended results⁹⁷</p> <p>Self-esteem: “one’s attitude towards oneself for one’s opinion or evaluation of oneself” (which may be positive or negative)⁹⁷</p>	<p>Parasuraman R., Riley V. (1997). Humans and automation: Use, misuse, disuse, abuse. <i>Human Factors</i>. https://doi.org/10.1518/001872097778543886</p> <p>Nam C.S., Lyons J.B. (eds) (2020). <i>Trust in human-robot interaction</i> 1st edition. Academic Press</p>
Vigilance	<ul style="list-style-type: none"> •The ability to maintain attention and respond to stimuli over extended periods¹¹¹ •The state or condition of being alert and attentive ⁹⁷ •Vigilance is defined as the capability to be aware of potential relevant, unpredictable changes in one's environment, including a quantitative dimension, a sufficient level of alertness, and a temporal dimension (van Schie et al., 2021) 	<p>Scerbo M.W. (2001). Stress, workload, and boredom in vigilance: A problem and an answer. In: P.A. Hancock, P.A. Desmond (eds), <i>Stress, workload and fatigue</i> (pp. 267-278). Mahwah, NJ: Lawrence Erlbaum Associates</p> <p>van Schie M. K., Lammers G. J., Fronczek R., Middelkoop H. A., van Dijk J. G. (2021). Vigilance: Discussion of related concepts and proposal for a definition. <i>Sleep Medicine</i>. https://doi.org/10.1016/j.sleep.2021.04.038</p>
Well-being	<p>Subjective well-being is formally defined by the “Organisation for Economic Co-operation and Development” (OECD) as good mental states, including the evaluations that people make of their lives, as well as their affective reactions to their experiences</p>	<p>https://www.oecd.org/wise/measuring-well-being-and-progress.htm</p> <p>https://www.oecd-ilibrary.org/economics/oecd-guidelines-on-measuring-subjective-well-being_9789264191655-en</p>

¹¹¹ Mackworth (1948), cited by Scerbo (2001)

B.3 Research & design centred on users

B.3.1 Definitions

Norman and Draper co-edited in 1986 a book titled ‘User centered system design: New perspectives on human computer interaction’⁷⁶, which was an output of the project User Centered System Design. They explained in the Introduction section that a pluralistic perspective¹¹² was needed to shift from the design of computer-based technology to the design of human-computer interaction under the **users’ point of view**. But as it was stressed by Brischetto (2020)¹¹³, the concept of user experience was not widely used until long after the usability concept, the goal of the user-centred approach being to improve the **usability** of system interfaces during the 1970s, 80s, and 90s; she defined the **user experience (UX)** as “the sum of emotions, perceptions and reactions that a person experiences when interacting with a product or service,” it is “a dimension of the design that revolves around the characteristics and needs of the user” (p. 51). She also emphasised the parallel progressive **shift from user-centred design to human-centred design**, which “was dictated by the increased complexity of daily-use products and technological innovation” (p.48).

The current ISO Standard is **ISO 9241-210:2019** (Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems), which “provides requirements and recommendations for human-centred design principles and activities throughout the life cycle of computer-based interactive systems¹¹⁴.” We keep the words “users-centred” along this chapter, to distinguish them from the concept of human factors, which we reserve for human-machine systems in dynamic situations.

There are many levels of users-centred approaches, for example, **co-creation** referring to “any act of collective creativity, i.e., creativity that is shared by two or more people” and **co-design** – a specific instance of co-creation – to “collective activity as it is applied across the whole span of a design process” (Sanders & Stappers, 2008¹¹⁵, p. 6), “the practice of collective creativity in

¹¹² “[...] many disciplines: computer science, psychology, artificial intelligence, linguistics, anthropology, and sociology—the cognitive science (Norman & Draper, 1986⁷⁶, pp. 1-2)

¹¹³ Brischetto A. From user-centred design to human-centred design and the user experience. In: Tosi F. (2020). *Design for ergonomics* (Chapter 3, pp. 47-59). Cham, Switzerland: Springer. <https://doi.org/10.1007/978-3-030-33562-5>

¹¹⁴ ISO 9241-210:2019 Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems: <https://www.iso.org/standard/77520.html> (accessed 24/06/2022)

¹¹⁵ Sanders E. B. N., Stappers P. J. (2008). Co-creation and the new landscapes of design. Co-design. <https://doi.org/10.1080/15710880701875068>

design has been around for nearly 40 years, going under the name of **participatory design**” (p. 7). **People-centric design** has a stronger focus on people and the public perspective (Tjark et al., 2021¹¹⁶). The **user & ecosystem centred design** approach – particularly relevant in the design of products or services for disabled people – considers explicitly not only the end user, but also the ‘ecosystem’ made up of stakeholders such as the family, caregivers, special needs workers, etc. (see Guffroy et al., 2017¹¹⁷, but also Blanchard et al., 2022¹¹⁸). As for **universal design**, it is defined in the United Nations’ Convention on the Rights of Persons with Disabilities as “the design of products, environments, programmes and services to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design” (Article 2¹¹⁹). Universal design was promoted by the American architect Ronald Lawrence Mace who contracted polio at age 9 as a philosophy of “design for all ages and abilities”¹²⁰. Universal design is initially based on seven principles¹²¹:

- **Equitable use**, i.e., “the design is useful and marketable to people with diverse abilities”;
- **Flexibility in use**, i.e., “the design accommodates a wide range of individual preferences and abilities”;
- **Simple and intuitive use**, i.e., “use of the design is easy to understand, regardless of the user’s experience, knowledge, language skills, or current concentration level”;
- **Perceptible information**, i.e., “the design communicates necessary information effectively to the user, regardless of ambient conditions or the user’s sensory abilities”;
- **Tolerance for error**, i.e., “the design minimizes hazards and the adverse consequences of accidental or unintended actions”;
- **Low physical effort**, i.e., “the design can be used efficiently and comfortably and with a minimum of fatigue”;

¹¹⁶ Gall T., Vallet F., Douzou S., Yannou B. (2021). Re-defining the system boundaries of human-centred design. *Proceedings of the Design Society, Volume 1: ICED21* 1, 2521-2530. <https://doi.org/10.1017/pds.2021.513>

¹¹⁷ Guffroy M., Nadine V., Kolski C., Vella F., Teutsch P. (2017). From human-centered design to disabled user & ecosystem centred design in case of assistive interactive systems. *International Journal of Sociotechnology and Knowledge Development*. <https://doi.org/10.4018/IJSKD.2017100103>

¹¹⁸ Blanchard E., Duvivier D., Kolski C., Lepreux S. (2022). Towards a framework for detecting temporary obstacles and their impact on mobility for diversely disabled users. In: Krömker H. (eds), *HCI in Mobility, Transport, and Automotive Systems. HCII 2022*. Lecture Notes in Computer Science. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-031-04987-3_32

¹¹⁹ <https://www.un.org/development/desa/disabilities/convention-on-the-rights-of-persons-with-disabilities/article-2-definitions.html> (accessed 27/06/2022)

¹²⁰ Ronald Mace: <https://www.britannica.com/biography/Ronald-L-Mace> (accessed 27/06/2022)

¹²¹ Story M.F., Mueller J.L., Mace R.L. (1998). *The universal design file: Designing for people of all ages and abilities*. Revised edition. Raleigh, NC: North Carolina State University. Center for Universal Design. <https://files.eric.ed.gov/fulltext/ED460554.pdf> (accessed 27/06/2022)

- **Size and space for approach and use**, i.e., “appropriate size and space is provided for approach, reach, manipulation, and use regardless of user’s body size, positive, or mobility”.

The overall goal of universal design is reflected by the word “regardless” repeated in the principles, that is, regardless of individual abilities and disabilities. This needs to consider accessibility under various perspectives: buildings and infrastructure, information and communication systems, education, cultures, etc.¹²²

The consequence is that the variables used in the evaluation stage of the universal design process are beyond the scope of this document.

B.3.2 Measurements in the users-centred design approach

Table 2 presents a list of variables and attributes which can be considered for the evaluation process in users-centred design approaches. As with Table 1, the list is not exhaustive. Table 2 is less homogeneous because of the great variety of variables: the human factors of Table 1 are marked with an asterisk (*) to refer readers to them; well-known system-related variables and attributes of the users-centred design approach are preceded by the symbol #. Variables related to the use of virtual reality are listed in Table 2 although these variables are not systematically associated with an approach centred on users; they are preceded by the superscript VR. Useful references: Kolski C. (ed) (2011). *Human-computer interactions in transport*. London: ISTE Ltd; Norman D. (2013). *The design of everyday things. Revised and expanded version*. New York: Basic Books; Tosi F. (2020). *Design for ergonomics*. Cham, Switzerland: Springer

¹²² See: Preiser W.E.F., Smith K.H. (eds) (2011). *Universal design handbook* Second edition. New York: McGraw-Hill

Table 2 Variables and attributes in the users-centred approach, per alphabetical order. Variables presented as human factors in Table 1 are preceded by an asterisk (*) referring to Table 1; well-known system-related variables and attributes of the users-centred design approach are preceded by the symbol #; well-known variables related to the use of virtual reality are preceded by the superscript VR

Variables and attributes	Definitions	References
*Acceptability		See also: Venkatesh V., Morris M. G., Davis G. B., Davis F. D. (2003). User acceptance of information technology: Toward a unified view. <i>MIS Quarterly</i> , 27(3), 425-478.
*Acceptance		
*Social acceptability		
# Accessibility	“Extent to which products, systems, services, environments and facilities can be used by people from a population with the widest range of user needs, characteristics and capabilities to achieve identified goals in identified contexts of use”	ISO 9241-210:2019 Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems ¹⁴
# Adaptation # Adaptability # Adaptivity	Adaptation is modelled in HCI as two complementary properties (Thevenin & Coutaz, 1999a) - Adaptability : “capacity of the system to allow users to customise their system from a predefined set of parameters” - Adaptivity : “capacity of the system to perform adaptation automatically without deliberate action from the user's part.” The design space for adaptation includes three additional orthogonal axes. See #Plasticity	Thevenin D., Coutaz J. (1999a). Adaptation and plasticity of user interfaces. In: <i>Proceedings to i3-spring99 Workshop on Adaptive Design of Interactive Multimedia Presentations for Mobile Users</i> . http://iihm.imag.fr/thevenin/papiers/I3Workshop99/I3Workshop99.pdf (accessed 27/06/2022) Thevenin D., Coutaz J. (1999b). Plasticity of user interfaces: Framework and research agenda. In. Sasse M.A., Johnson C. (eds), <i>Human-Computer Interaction–INTERACT’99</i> . Amsterdam: IOS Press. http://iihm.imag.fr/publs/1999/interact99_plasticite.pdf (verified on 27/06/2022)
Adoption	Adoption of a technology is a process going from acceptability to effective acceptance (Bobillier-Chaumon & Dubois, 2009). According to Rogers, the five following perceived attributes of an innovation are an important explanation of its adoption: relative advantage (“the degree to which an innovation is perceived as being better than the idea it supersedes”); compatibility (“the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters”); complexity (“the degree to which an innovation is perceived as relatively difficult to understand and use”); trialability (“the degree to which an innovation may be experimented with on a limited basis”); observability (“the	Bobillier-Chaumon M. E., Dubois M. (2009). Technology acceptance and acceptability in organisations. <i>Le travail humain</i> . https://doi.org/10.3917/th.724.0355 Rogers E.M. (2003). <i>Diffusion of innovations</i> Fifth edition. New York: Free Press

	degree to which the results of an innovation are visible to others”)	
Affordance (suggestibility) # Signifiers	<p>According to Norman (2013), affordances refer to the possible interactions between people and the environment, they define what actions are possible; but in design, signifiers (i.e., signs, perceptible signals) are more important than affordances, signifiers communicate where the action should take place</p> <p>According to Dinet (2021), biomechanical and perceptual factors are important in the design of signifiers, but there are also semantic, social and cultural constraints</p>	<p>Dinet J. (2021). Affordance – suggestibilité [Affordance – suggestibility]. In: Brangier É., Valléry G. (dir) (2021). <i>Ergonomie : 150 notions clés</i> (pp. 96-99). Malakoff, France: Dunod</p> <p>Norman D. (2013). <i>The design of everyday things. Revised and expanded version</i>. New York: Basic Books</p>
*Attention		
Comfort Discomfort	<p>Comfort: generally defined as feelings of relaxation and well-being, a state of subjective well-being affected by factors of a various nature (physical, physiological, psychological) and which is a reaction to an environment or a situation (see de Looze et al., 2003, p. 986)</p> <p>Discomfort: in the literature, either comfort and discomfort are treated as one variable on one continuum or they are considered as distinct with different underlying constructs (important distinction to develop relevant questionnaires). Feelings of discomfort are associated with pain, tiredness, soreness, and numbness (see de Looze et al., 2003, p. 987)</p>	<p>De Looze M.P., Kuijt-Evers L.F.M., van Dieën J. (2003). Sitting comfort and discomfort and the relationships with objective measures. <i>Ergonomics</i>. https://doi.org/10.1080/0014013031000121977</p> <p>Vink P. (2005). <i>Comfort and discomfort. Principles and good practice</i>. Boca Raton, FL : CRC Press</p>
VR Cybersickness	<p>Both cyber sickness and motion sickness produce eye strain, headache, pallor, sweating, disorientation, vertigo, ataxia, nausea, etc., but they are not necessarily the same thing: vestibular stimulation alone can be sufficient to induce motion sickness, while cyber sickness can occur strictly with visual simulation (La Viola 2000)</p> <p>The Institute of Electrical and Electronics Engineers¹²³ defines cyber sickness as psychological and physiological symptoms similar to those of motion sickness during or as a</p>	<p>La Viola Jr. J.J. (2000). A discussion of cyber sickness in virtual environments. <i>ACM SIGCHI Bulletin</i>. https://doi.org/10.1145/333329.333344</p> <p>Salimi Z., Ferguson-Pell M. W. (2021). Motion sickness and sense of presence in a virtual reality environment developed for manual wheelchair users, with three different approaches. <i>PloS one</i>. https://doi.org/10.1371/journal.pone.0255898</p>

¹²³ IEEE Standard for Head-Mounted Display (HMD)-Based Virtual Reality(VR) Sickness Reduction Technology. In: IEEE Std 3079-2020, 29 April 2021. <https://ieeexplore.ieee.org/servlet/opac?punumber=9416948> (accessed 28/06/2022)

	<p>result of experiencing virtual environments, especially using head-mounted displays</p> <p>Simulator sickness is defined as the experience of motion sickness within a virtual environment. The main theory underlying this sickness postulates that while in VR there is a disconnect between what the vestibular system is experiencing (standing still) and what the eyes are experiencing (moving around in a virtual environment) (Spain et al., 2019¹²⁴)</p>	
Effectiveness	<p>Accuracy and completeness with which users achieve specified goals (ISO 9241-210:2019¹¹⁴)</p> <p>Two measures of effectiveness: task achievement and performance quality (Brangier & Barcenilla, 2003, p. 44)</p>	Brangier É., Barcenilla J. (2003). <i>Concevoir un produit facile à utiliser. Adapter les technologies à l'homme</i> [Designing a product that is easy to use. Adapting technologies to people]. Paris : Éditions d'Organisation
Efficiency	<p>Relationship between the result achieved and the resources used (time, human effort, cost and materials resources)¹¹⁴</p>	ISO 9000:2015 Quality management systems — Fundamentals and vocabulary. https://www.iso.org/standard/45481.html (accessed 28/06/2022)
^{VR} Engagement	<p>“Willingness to have emotions, affect, and thoughts directed toward and aroused by the mediated activity in order to achieve a specific objective”</p>	Bouvier P., Lavoué E., Sehaba K. (2014). Defining engagement and characterizing engaged-behaviors in digital gaming. <i>Simulation & Gaming</i> . https://doi.org/10.1177/1046878114553571

¹²⁴ Spain R. et al. (2019). Applications of virtual environments in human factors research and practice. In: *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (<https://doi.org/10.1177/1071181319631393>). Los Angeles, CA: SAGE Publications.

<p># Ergonomic criteria</p>	<p>The famous so-called « ergonomic criteria of Bastien & Scapin or Scapin & Bastien » are a set of usability dimensions to evaluate user interfaces:</p> <p># Guidance: how the interface advises, orients, informs, instructs, and guides the users throughout their interactions</p> <p># Workload: how all interface elements contribute to reducing the users’ perceptual and cognitive load, and to increase the dialogue efficiency</p> <p># Explicit control: how explicit the relationship between the users’ actions and the computer processing is and what the users’ level of control over the system processing is</p> <p># Adaptability: how the system behaves contextually according to users’ needs and preferences</p> <p># Error management: what the means available to prevent or reduce errors and to recover from them when they occur are</p> <p># Consistency: how the interface design choices (codes naming, procedures, etc.) are consistent in similar contexts and different in different contexts</p> <p># Significance of codes: how the relationship between a term and/or sign and its reference is</p> <p># Compatibility : for a given task, how compatible are the user’s characteristics (memory, perceptions, skills, age, expectations, habits) and the organisation of the output, input and dialogue</p>	<p>Bastien J.M.C., Scapin D.L. (1992). A validation of ergonomic criteria for the evaluation of human-computer interfaces. <i>International Journal of Human-Computer Interaction</i>. https://doi.org/10.1080/10447319209526035</p> <p>Table 1. List of Criteria</p> <hr/> <ol style="list-style-type: none"> 1. Guidance <ol style="list-style-type: none"> 1.1. Prompting 1.2. Grouping and distinguishing items <ol style="list-style-type: none"> 1.2.1. Grouping and distinguishing items by location 1.2.2. Grouping and distinguishing items by format 1.3. Immediate feedback 1.4. Clarity 2. User workload <ol style="list-style-type: none"> 2.1. Brevity <ol style="list-style-type: none"> 2.1.1. Concision 2.1.2. Minimal actions 2.2. Mental load 3. User-explicit control <ol style="list-style-type: none"> 3.1. Explicit actions 3.2. User control 4. Adaptability <ol style="list-style-type: none"> 4.1. Flexibility 4.2. Users’ experience management 5. Error management <ol style="list-style-type: none"> 5.1. Error protection 5.2. Error messages 5.3. Error correction 6. Consistency 7. Significance of codes 8. Compatibility <hr/> <p><i>Note. Elementary criteria are in boldface.</i></p> <p>Figure 43 Ergonomic criteria. Source: Bastien & Scapin, 1992, p. 187</p> <p>Bastien J.M.C., Scapin D.L. (1995). Evaluating a user interface with ergonomic criteria. <i>International Journal of Human-Computer Interaction</i>. https://doi.org/10.1080/10447319509526114</p> <p>Scapin D.L., Bastien J.M.C. (1997). Ergonomic criteria for evaluating the ergonomic quality of interactive systems. <i>Behaviour & Information Technology</i>. https://doi.org/10.1080/014492997119806</p>
<p>^{RV}Flow</p>	<p>Being in flow refers to a “subjective experience of engaging just-manageable challenges by tackling a series of goals, continuously processing feedback about progress, and adjusting action based on this feedback”; it is characterised by intense and focused concentration on what one is doing in the present moment, merging of action and awareness, loss of awareness of oneself as a social actor, a sense that one can control one’s actions (Nakamiura & Csikszentmihalyi, 2014, p. 240)</p>	<p>Nakamura J., Csikszentmihalyi M. (2014). The concept of flow. In: Csikszentmihalyi M., <i>Flow and the foundations of positive psychology. The collected works of Mihaly Csikszentmihalyi</i> (pp. 239-263). Dordrecht, Netherlands: Springer</p> <p>Cheng L.K., Chieng M.H., Chieng, W.H. (2014). Measuring virtual experience in a three-dimensional virtual reality interactive simulator environment: A structural equation modeling approach. <i>Virtual Reality</i>. https://doi.org/10.1007/s10055-014-0244-2</p>

	Flow is a component of UX in immersive virtual environment according to Tcha-Tokey et al. (2016)	Tcha-Tokey K., Christmann O., Loup-Escande E., Richir S. (2016). Proposition and validation of a questionnaire to measure the user experience in immersive virtual environments. <i>International Journal of Virtual Reality</i> . https://doi.org/10.20870/IJVR.2016.16.1.2880
# Hedonic quality Perceived hedonic quality	<p>According to Hassenzahl et al. (2000), the quality dimensions of a software system could be categorised into ergonomic quality (EQ) and hedonic quality (HQ)</p> <p>EQ refers to traditional usability (efficiency and effectiveness), while HQ “comprises quality dimensions with no obvious relation to the task the user wants to accomplish” and /or affective quality</p> <p>Examples of HQ: innovativeness, originality and/or pleasure, enjoyment, fun (see also Hassenzahl, 2007)</p> <p>Perceived hedonic quality can be assessed by a questionnaire</p>	<p>Hassenzahl M., Platz A., Burmester M., Lehner K. (2000). Hedonic and ergonomic quality aspects determine a software's appeal. In: <i>Proceedings of the SIGCHI conference on Human factors in Computing Systems</i> (pp. 201-208). https://doi.org/10.1145/332040.332432</p> <p>Hassenzahl M. (2001). The effect of perceived hedonic quality on product appealingness. <i>International Journal of Human-Computer Interaction</i>. NY: ACM. https://doi.org/10.1207/S15327590IJHC1304_07</p> <p>Hassenzahl M. (2006). Hedonic, emotional, and experiential perspectives on product quality. In: Ghaoui C. (ed), <i>Encyclopedia of Human Computer Interaction</i> (pp. 266-272). Hershey, PA: Idea Group Reference</p>
^{RV} Immersion ^{RV} Degree of immersion	<p>A general model for VR would define three levels of immersion and interaction: sensorimotor level through behavioural interfaces; functional level through functionality (task level), and cognitive level, the latter referring to the subjective aspect of immersion: the user must be mentally immersed in the virtual world (Fuschs et al., 2011)</p> <p>This subjective aspect of immersion can be defined as the “sensation of being physically immersed in a 3D virtual world”¹²⁵; it is a sensation, it can thus be assessed by questionnaire</p> <p>The objective degree of immersion can be defined as the “degree of the realism of immersion, depending on the number of senses that are simulated and stimulated by the virtual reality system and the level of isolation of the user from the real world”¹²⁵</p>	<p>Fuchs P., Burkhardt J.-M., Lourdeaux D. (2011). Theoretical and pragmatic approach to virtual reality. In: Fuchs P., Moreau G., Gutton P. (eds), <i>Virtual reality: Concepts and technologies</i> (Chapitre 2). Boca Raton, FL: CRC Press</p> <p>‘Vocabulary of virtual reality’ in French, published online by the Canadian Office québécois de la langue française¹²⁵</p>
Patient experience (PX)	Patient experience is about the quality, expectations and satisfaction related to the interactions of patients and their	https://www.theberylinstitute.org/page/DefiningPX (accessed 29/06/2022)

¹²⁵ <https://www.oqlf.gouv.qc.ca/ressources/bibliotheque/dictionnaires/vocabulaire-realite-virtuelle.aspx> (accessed 29/06/2022)

	families with clinical and non-clinical actors along the health care pathway, with the resulting perceptions also being shaped by the culture of the health care organisation (strategies, values)	<p>Wolf J.A., Niederhauser V., Marshburn D., LaVela S.L. (2014). Defining patient experience. <i>Patient Experience Journal</i>. https://pxjournal.org/journal/vol1/iss1/3/</p> <p>Idoughi D., Touloum K., Guerrier Y., Kolski C. (2022). Perspectives on the patient experience (PX) of people with disabilities in the digital age: From UX to PX. In: Chaabane S., Cousein E., Wieser (eds), <i>Healthcare Systems: Challenges and Opportunities</i> (Chapter 10). London: ISTE and Hoboken, NJ: John Wiley & Sons. https://doi.org/10.1002/9781119902614.ch10</p> <p>Bernardo J. M. S., Mendes G. H. D. S., Lizarelli F. L., Roscani M. G. (2022). Instruments to measure patient experience in hospitals: a scoping review. <i>Gestão & Produção</i>. https://doi.org/10.1590/1806-9649-2022v29e0821</p>
Perceived ease of use	<p>Perceived ease of use is “the degree to which a person believes that using a particular system would be free of effort” (Davis, 1989, p. 320)</p> <p>According to Davis, both perceived ease of use and perceived usefulness are important determinants of user acceptance of the system</p>	<p>Davis F.D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. <i>MIS Quarterly</i>. https://doi.org/10.2307/249008</p>
Perceived usefulness	<p>The degree to which a person believes that using a particular system would enhance his/her performance (Davis, 1989, p. 320).</p> <p>According to Davis, both perceived usefulness and perceived ease of use are important determinants of user acceptance of a system</p>	<p>Davis F.D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. <i>MIS Quarterly</i>. https://doi.org/10.2307/249008</p>
# Personalisation	<p>In computer science, personalisation of an interactive system refers to making it more responsive to the unique and individual needs of each user (Cingil et al., 2000)</p> <p>Personalization of the information delivered to the user consists in adapting it to his/her goals, preferences, and/or capabilities (Brossard et al., 2011)</p>	<p>Cingil I., Dogac A., Azgin A. (2000). A broader approach to personalization. <i>Communications of the ACM</i>. https://doi.org/10.1145/345124.345168</p> <p>Brossard, A., Abed, M., & Kolski, C. (2011). Taking context into account in conceptual models using a Model Driven Engineering approach. <i>Information and Software Technology</i>. https://doi.org/10.1016/j.infsof.2011.06.011</p>

<p># Plasticity</p>	<p>Plasticity is the “capacity of a user interface to withstand variations of both the system physical characteristics and the environment while preserving usability”</p> <p>Plasticity is a particular type of adaptation (see #Adaptation); the latter can be described through the following axes (Figure 44):</p> <ul style="list-style-type: none"> - Target axis: adaptation to users, the environment, or the physical characteristics of the system - Means Axis regarding the software components involved adaptation: task model, rendering techniques, or help subsystems - Time Axis: adaptation is either static or dynamic - Actor Axis: adaptation is performed automatically or on human request <p>Plasticity is concerned with the variations of the environment and/or the characteristics of the user of the target axis, and with the modification of the task model and/or the rendering techniques of the mean axis</p>	<p>Thevenin D., Coutaz J. (1999a). Adaptation and plasticity of user interfaces. In: <i>Proceedings to i3-spring99 Workshop on Adaptive Design of Interactive Multimedia Presentations for Mobile Users</i>. http://iihm.imag.fr/thevenin/papiers/I3Workshop99/I3Workshop99.pdf (accessed 27/06/2022)</p> <p>Thevenin D., Coutaz J. (1999b). Plasticity of user interfaces: Framework and research agenda. In. Sasse M.A., Johnson C. (eds), <i>Human-Computer Interaction–INTERACT’99</i>. Amsterdam: IOS Press. http://iihm.imag.fr/publs/1999/interact99_plasticite.pdf (accessed 27/06/2022)</p> <p>Kolski C. (ed) (2011). <i>Human-computer interactions in transport</i>. London: ISTE Ltd</p> <div data-bbox="1276 602 1703 987" data-label="Diagram"> </div> <p>Figure 44 The design space for adaptation. Source: Thevenin & Coutaz, 1999b, p.2</p>
<p>Presence</p>	<p>Mestre and Vercher (2011) considered that immersion should be reserved for the objective characteristics of a VR system, while presence would be the effect that this immersion produces on the behaviour of the user.</p> <p>Witmer and Singer (1998) defined presence as a psychological state of ‘being there’ mediated by an environment that engages our senses, captures our attention, and fosters our active involvement.</p> <p>According to Tcha-Tokey et al. (2016), presence, the sense of being there in the virtual environment (VE), include physical presence in the VE and social presence in the</p>	<p>Mestre D., Vercher J.-L. (2011). Immersion and presence. In: Fuchs P., Moreau G., Gutton P. (eds), <i>Virtual reality: Concepts and technologies</i> (Chapitre 5). Boca Raton, FL: CRC Press</p> <p>Tcha-Tokey K., Christmann O., Loup-Escande E., Richir S. (2016). Proposition and validation of a questionnaire to measure the user experience in immersive virtual environments. <i>International Journal of Virtual Reality</i>. https://doi.org/10.20870/IJVR.2016.16.1.2880</p> <p>Witmer B.G., Singer M.F., 1998, Measuring presence in virtual environments: A presence questionnaire. <i>Presence: Teleoperators and Virtual Environments</i>. https://doi.org/10.1162/105474698565686</p>

	collective or collaborative in the VE; these authors consider presence as one of the components of UX in immersive virtual environment	
Satisfaction	<p>“Extent to which the user's physical, cognitive and emotional responses that result from the use of a system, product or service meet the user’s needs and expectations</p> <p>Note 1 to entry: Satisfaction includes the extent to which the user experience that results from actual use meets the user’s needs and expectations.</p> <p>Note 2 to entry: Anticipated use can influence satisfaction with actual use.”</p>	<p>ISO 9241-11:2018 Ergonomics of human-system interaction — Part 11: Usability: Definitions and concepts https://www.iso.org/obp/ui/fr/#iso:std:iso:9241:-11:ed-2:v1:en</p>
# Usability	<p>ISO 9241-11:2018: “Extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use</p> <p>Note 1 to entry: The ‘specified’ users, goals and context of use refer to the particular combination of users, goals and context of use for which usability is being considered</p> <p>Note 2 to entry: The word “usability” is also used as a qualifier to refer to the design knowledge, competencies, activities and design attributes that contribute to usability, such as usability expertise, usability professional, usability engineering, usability method, usability evaluation, usability heuristic”</p> <p>“Suitability of an object for the use for which it was designed and implemented” and the “ease with which people can use it” (In Tosi, 2020)</p> <p>According to Brangier and Barcenilla (2021), the three following components of usability are fundamental: i/ effectiveness (i.e., a system is effective if it produces the effect expected by the user) ; ii/ efficiency (in terms of the ratio between spent resources and obtained result: the lower the effort, the higher the efficiency) ; iii/ satisfaction (subjective evaluation of the comparison between what the utilization of the systems brings to the user and what the user expects to receive)</p>	<p>ISO 9241-11:2018 Ergonomics of human-system interaction — Part 11: Usability: Definitions and concepts https://www.iso.org/obp/ui/fr/#iso:std:iso:9241:-11:ed-2:v1:en</p> <p>Brangier É., Barcenilla J. (2021). Utilisabilité [Usability]. In : Brangier É., Valléry G. (dir) (2021). <i>Ergonomie : 150 notions clés</i> (pp. 537-539). Malakoff, France : Dunod</p> <p>Tosi F. (2020). <i>Design for ergonomics</i>. Cham, Switzerland: Springer</p>

	<p>“User’s perceptions and responses that result from the use and/or anticipated use of a system, product or service. Note 1 to entry: Users’ perceptions and responses include the users’ emotions, beliefs, preferences, perceptions, comfort, behaviour, and accomplishments that occur before, during and after use”¹⁴</p>	
User experience (UX)	<p>User experience is about the relationship developed by a person interacting with a given system. It is both a functional experience at the level of interaction with the system and a personal experience: the former refers to usability and ergonomic criteria, the latter to hedonic aspects such as aesthetics, comfort, pleasure and other feelings (Bastien & Brangier, 2021).</p> <p>Subjective aspects of UX can be assessed by a questionnaire (e.g., Tcha-Tokay et al. (2016))</p>	<p>Bastien C., Brangier É. (2021). Expérience utilisateur. In: Brangier É., Valléry G. (dir) (2021). <i>Ergonomie : 150 notions clés</i> (pp. 292-296). Malakoff, France: Dunod</p> <p>Tcha-Tokey K., Christmann O., Loup-Escande E., Richir S. (2016). Proposition and validation of a questionnaire to measure the user experience in immersive virtual environments. <i>International Journal of Virtual Reality</i>. https://doi.org/10.20870/IJVR.2016.16.1.2880</p>
# Validation	<p>“Confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled</p> <p>Note 1 to entry: validation is the set of activities ensuring and gaining confidence that a system is able to accomplish its intended use, goals and objectives (i.e. meet stakeholder requirements) in the intended operational environment”</p>	<p>ISO 9241-210:2019 Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems: https://www.iso.org/standard/77520.html (accessed 24/06/2022)</p>
# Verification	<p>“Verification is a set of activities that compares a system or system element against the required characteristics. This can include, but is not limited to, specified requirements, design description and the system itself”</p>	
Wow experience	<p>Wow is an emotional experience that combines fascination, desire, and pleasant surprise (Desmet et al., 2007)</p>	<p>Desmet P.M.A., Procelijn R., van Dick M.B. (2007). Emotional design; Application of a research-based design approach. <i>Knowledge, Technology & Policy</i>. https://doi.org/10.1007/s12130-007-9018-4</p> <p>Norman D.A. (2005). <i>Emotional design: Why we love (or hate) everyday things</i>. New York: Basic Books</p>