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Universal design and social care: Assistive robots as other users of the built environment?

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Abstract: The importance of designing architecture and physical environment using the Universal Design method so that all people have the opportunity to reside and participate in the environment has long been recognised. This design approach is even more important in housing for older adults and people with disabilities. However, even in environments designed according to universal design principles, the assistance of human staff is often necessary. We consider some of the routine and physically demanding activities of caregivers could be possibly replaced by robots. This would offer people who require care a greater degree of independence and relieve the burden on staff to give them more time for activities that robots cannot yet do. Robotics is a discipline covering various aspects of robot design and use. Apparently, numerous robots and robotic devices being developed for the social or healthcare sector, called Assistive Robots, are still in the concept, design or testing phase. However, this may change with the increasing investment in robotics and there is a need to be realistic about their possible use in the near future. Another considered robot type is a Butler or Service Robot which helps with delivering various objects including food or medicine. These types of robots require a barrier-free, accessible space to move around, similar to what people in wheelchairs or bedridden persons need for their movement and transfer. This paper publishes the results of a simulation of Assistive and Butler Robots in an extra-care housing facility, where social services with the help of robots are to be provided in the future. Manoeuvring of people and robots is simulated in a floorplan of the chosen model project of a family type house. Research aims to investigate the robots' spatial requirements in a building project designed in accordance with universal design principles. The paper concludes with several answers to the questions posed and recommendations for the creation of residential buildings that support the symbiosis of humans and robots.

Keywords: architecture, built-environment, universal design, assistive robot, butler robot, social care

INTRODUCTION

Population ageing is a serious problem, as confirmed by the results of all known national and international population projections. The negative impact of population ageing is manifested in almost all areas, especially threatening the sustainability of social and economic systems. From the point of view of public policies aimed at supporting the development of social services, it is not only the indicators of the growing number of older adults in the total population that are crucial, but also their health indicators, which determine their self-sufficiency and independence, or dependence on the help of another person in everyday life. *"According to the current mortality tables, men aged 65+ in Slovakia may live another 15.3 years and women 19.2 years, but men will survive only 3.8 years and women only 4.1 years of this period in good health"* (Ministry of Labour, Social Affairs and Family of the Slovak Republic, 2021, p. 6). The strain on social and health systems requires much more funding, but also an increased number of carers, assistants and nurses, who are in demand in almost every country. Therefore, solutions are being sought to help people in need of care while also relieving the burden on care staff through technological innovations, including robots. Assistive robots can help older adults and people with disabilities to move around, perform daily activities and enjoy their environment (Fasola, Matarić, 2013), even enabling them to remain living in their home environment (Balaguer, Giménez, Jardón, Correal, Martínez, Sabatini, Genovese, 2007), which is in line with the current trend of deinstitutionalisation of social services. The current question is: can robots replace the hard work of carers and caregivers?

The topic of the use of robots in care providing has been the subject of much research for more than 10 years, and several papers have been published in this context (Broekens, Heerink, Rosendal, 2009; Bemelmans, Gelderblom, Jonker, de Witte, 2010; Bemelmans, Gelderblom, Jonker, de Witte, 2012; Prescott, Caleb-Solly, 2017; Cifuentes, Pinto, Céspedes, Múnera, 2020; Andtfolk, Nyholm, Eide, Fagerström, 2022). *"There is growing interest among care providers, charities, and academics in using robotics to improve the quality of care and ease pressure on the social care system"* (Wilson, Kenny, 2018, p. 1). The need to explore the potential of robots has also been declared: *"We know that carers are critical to the increasingly fragile care sector, but being a carer impacts individuals emotionally, mentally, financially and physically. Our discovery phase focussed on the potential for robotic solutions to help address the physical impact of caring"* (Isle of Wight Council, 2018, p. 2). Putting human safety first, it is important to test the transfer of a dependent human in the context of assistive robots' centre of gravity retention. Several experiments with such robots show effective real-time imitation and dynamic behaviour adaptation (Arduengo, Arduengo, Colomé, Lobo-Prat, Torras, 2021); optimal motion also in relation to the gravitational acceleration is being calculated (Kim, Kim, 2023). However, it is an active area of research and development, and any type of a new assistive robot that carries people must first pass stability tests. When analysing the available literature, we mainly searched for papers where the relationship between assistive robots and the built environment is discussed. An important piece of information is that a barrier-free environment is ideal for a robot, similar to that of older adults or people with various disabilities. Thus, our research aims to deepen the knowledge in the field of accessible environment design, specifically in the universally designed environment of social service facilities.

Today's inaccessible built environments are the result of inattention to the needs of diverse users. The term "architectural disability" (Goldsmith, 1997) probably best describes the relationship between disability and the environment. Barrier environments severely restrict people with disabilities and hinder their inclusion; this is also true for older adults. At the turn of the millennium, a movement emerged in the field of architecture and design that promotes a new way of thinking that focuses on the needs of people, called human-centred design, which has several streams – Universal Design, Design for All, or Age-Friendly Design, among others. In many strategies and international documents, accessible environments are considered essential and one of the conditions for achieving sustainability of social and economic systems.

In the UN Convention on the Rights of Persons with Disabilities (United Nations, 2006, Article 2), "*'Universal design' means 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 specialised design. 'Universal design' shall not exclude assistive devices for particular groups of persons with disabilities where this is needed.*" It is clear from the definition that it is not just about designing for people with disabilities, but designing for "all people". For people with disabilities, but also for older adults with a variety of health impairments, an accessible environment is essential because it enables them to be more independent. It should be noted that the definition of universal design recognises that "assistive devices" may be used for certain groups of people. This means the use of a variety of technological devices and assistive aids that help people with disabilities to "function" in the community with as little dependency as possible (e.g. aids to overcome architectural barriers in the built environment, induction loops for communicating with people with hearing impairments, guiding lines, navigation systems and special software for people with visual impairments, etc.).

Implementing assistive robots is also significant when caring for a person with an infectious disease, as it prevents the spread of infection in comparison to care by human assistants (Holland, Kingston, McCarthy, Armstrong, O'Dwyer, Merz, McConnell, 2021). When caring for people with various diagnoses, the use of different robots providing diverse help needs to be considered. There are for example several assistive robots that have been developed to help people with dementia, providing companionship, safety checks and engagement in activities and events (Ozdemir, Cibulka, Stepankova, Holmerova, 2021; Law, Sutherland, Ahn, MacDonald, Peri, Johanson, Vajsakovic, Kerse, Broadbent, 2019), or a soft robotic glove designed to facilitate home-based rehabilitation for stroke survivors with hand impairment (Polygerinos, Wang, Galloway, Wood, Walsh, 2015), and many other specialised assistive robots. Of course, each diagnosis and also each individual require different approach concerning robots, so every case has to be considered separately.

As mentioned above, today it is also necessary to consider the use of assistive robots helping people with various needs and also butler robots, which could replace some of the activities related to household maintenance, and perform more difficult activities that are currently carried out by personal assistants or carers.

THE POTENTIAL OF ROBOTS IN SOCIAL CARE BUILDINGS

When investigating the relationship between robots and the built environment, it is necessary to analyse the robots' ability to move in the environment, and also the possible ways of handling various objects, studying the robots' possible actions in the environment in which social services are provided. It is also important to create an infrastructure for locating robots in the indoor environment, recharging them, and ensuring the appropriate type of wireless communication between the robot and the building's infrastructure.

Different types of robots' movement in the environment

A robot that is designed to assist in loading or carrying loads in cooperation with a human operator will have a different construction from that handling objects by itself and must therefore be equipped with one or two handling hands with a suitable type of gripper capable of grasping the relevant object(s) without damaging them. A big challenge for the robot is mounting or descending stairs or overcoming other vertical obstacles. If the robot moves using wheels, it can be easily deduced that the force required to overcome a step-like obstacle with its height compared to the radius of the wheel increases sharply to infinity when reaching a height equal to the radius of the wheel. At an obstacle height equal to 68% of the wheel radius, the force required to overcome the obstacle is three times the wheel's weight.

We will consider this variant as borderline due to the power limitations of the mobile robot drives. Therefore, we can talk about overcoming step-like obstacles only with a height less than 1/3 of the wheel diameter. Equipping the robot with a suspension chassis (which is not standard for robots intended for indoor environments) or even an active mechanism that lifts the wheel when passing an obstacle, this limit can be slightly increased. For example, a door threshold with a height of 2 centimetres can be insurmountable for a robot with smaller wheels (e.g., swivel wheels in the case of differential chassis). The robot should also overcome small fallen items, cables on the ground, or a wavy carpet. The ground clearance of the chassis can also be a limiting factor, which is, for understandable reasons, limited by the radius of the robot's drive wheels.

Walking chassis with 2, 4, or 6 legs represent the ultimate solution in terms of the ability to overcome obstacles. However, they are more likely to be used in applications outside of urbanised areas and are structurally more complex and, therefore, much more expensive than robots with wheeled chassis. A compromise can be the application of chassis with rubber tracks. However, they can destroy the used floor surfaces, especially during turning manoeuvres. In addition to the limited speed of motion, they also have other disadvantages in indoor spaces. Furthermore, it is necessary to consider that the robot spends a lot of energy when overcoming obstacles, which could be used more efficiently for the tasks for which it is intended. For the use of a robot as a human assistant in a social services building, it is optimal to ensure a completely barrier-free environment. The limited performance of the robot's drives, especially when transporting heavy loads, will also result in a limited ability to drive on an inclined surface. In extreme cases, impaired chassis stability can also play a role, which would be in danger of overturning. Through testing and calculating, we have found that robots can also overcome barrier-free ramps, implemented for the motion of people in wheelchairs, but again at the expense of higher energy consumption.

Another limitation of the motion of mobile robots in an indoor environment is their ability to manoeuvre in confined spaces. In this sense, the omnidirectional chassis is the best – either based on 3 or 4 standard wheels (while each wheel has a pair of motors, which allow simultaneous turning and driving of individual wheels) or based on 3 or 4 omnidirectional wheels of standard or Swedish type (Mecanum wheels). In the first case, we encounter the problem with the price of the solution due to the necessary number of motors and electronics related to their control, and in the second, the fact that the limited possibility mentioned in the previous paragraph when overcoming step-like obstacles refers to the diameter of small passive rollers located around the circumference of the main wheel.

Chassis with a differential drive without supporting wheels (of the Segway or dicycle type) or with some supporting wheels (often of swivel type) have slightly worse manoeuvrability. The supporting wheels are typically smaller in size, which can cause previously mentioned problems with overcoming step-like obstacles. Bigger wheels could be used for a Segway-type robot, but this type of chassis is not very convenient in terms of energy consumption given the constant need to stabilise the body. Its safety when interacting with people with mobility restrictions is also questionable. Robots based on differential chassis cannot move to the side, and their motion trajectories are composed of circular arcs with any radius – at zero radii, it is rotation in place, and at infinite radius, it is rectilinear motion. The lateral motion must be composed of a sequence – turning in place, moving in the desired direction, and, if necessary, turning to the original orientation. When rotating in place, it is necessary to ensure a free space corresponding to the largest dimension of the robot's footprint.

The car-like, so-called Ackerman chassis has the worst manoeuvrability, which can only move in circular arcs from minimum radius to infinity. Unlike a differential chassis, it cannot turn around its centre. When operating in limited spaces, it requires the implementation of a sequence of several manoeuvres in both directions – exactly in the style of parking manoeuvres of a car. In addition to the above-mentioned aspects, it is necessary to ensure a sufficient wireless data network signal for robots in the entire operating space because a robot must communicate both with the infrastructure of the building (doors, elevators, lights, security systems) and with the higher level computers (which have much higher computing and memory capacity) when solving more complex tasks, coordinating robot's work, during software updates, etc. For specific operations (such as transmission of a larger volume of data, video transmission), it may be necessary to ensure a stable connection with sufficient transmission bandwidth.

Robot infrastructure in the environment

Another condition for the undisturbed work of assistive mobile robots is the existence of a charging infrastructure. Like a mobile phone or an electric car, a mobile robot has a limited operating time and must be charged when such time expires. There are contact chargers in the style that robotic vacuum cleaners use today, or inductive-type charging can be used. In the second case, the robot can receive by induction the energy within a certain space in which electromagnetic waves of the desired properties are available at sufficient intensity. Where continuous robot availability is required, such charging option can be offered in certain parts of the track along which the robots move most frequently. However, the use of electromagnetic wave charging is not suitable for buildings for human occupancy in view of the anticipated health risks. Another option is to provide a redundant number of robots, some of which are working at a given moment and the rest are being recharged.

Finally, for the application of mobile robots in indoor spaces, it is necessary to ensure the infrastructure for their localization given the absence of a GPS signal inside the building. With today's technological possibilities, this can be ensured either by a system of radio beacons located at the edges of the operating space or by means of optical markers without obstacles visible from the path along which the robots are moving. Typically, such signs are installed on the ceiling or on walls at a greater height, where there is no risk of overlapping with parts of the interior, their pollution, or other damage. For the navigation of robots based on visual systems, sufficient lighting is also necessary, which can be ensured by existing lighting remotely turned on by the robot itself. Alternatively, when working in dark spaces, it is possible to use infrared vision with illumination by its own source of infrared radiation on the robot.

In human-robot communication, various ways are possible, e.g., voice commands and hand gestures. If these are repetitive and well-definable actions (help when getting out of bed, help when walking to the toilet, to common areas, etc.), simple voice communication specifying the trip's destination or the required action would be sufficient. With non-standard requests, it would be possible to combine this type of communication with hand gestures when the operator can call the robot to them, give commands for different types of motions, and the like.

RESEARCH MATERIALS AND METHODS

A team of experts in Universal Design and Robotics from the Slovak University of Technology in Bratislava, Slovakia, investigated whether it is possible to reconcile the demands of humans and robots in the built environment and whether the environment designed according to the preferred Universal Design method would be suitable for the functioning of Assisted Robots. The following research question was hypothesised: Can a building that is designed according to Universal Design principles be suitable for Assistive Robots?

For the purposes of the investigation, a building known as supported housing was selected, in which the social service is to be provided. The selected model project Type B – Family type house (Rollová, Filová, 2022) is one of 20 model architectural studies of buildings suitable for providing community-based services, designed at the Faculty of Architecture and Design of the Slovak Technical University in Bratislava, Slovakia. The catalogue of architectural studies was prepared for investment purposes within the framework of the Recovery and Resilience Plan of Slovakia, Component 13 – Affordable and quality long-term social and health care, commissioned by the Ministry of Labour, Social Affairs and Family of the Slovak Republic. All model designs of buildings for the provision of community-based social services take into account the basic principles of Universal Design and the requirements of the European standard EN 17210:2021 Accessibility and usability of the built environment – Functional requirements.

The selected model building, Type B – Family type house, is an adaptable house with a capacity of 4 to 12 inhabitants, depending on the needs of the service provider, location or size of the plot. This building consists of specialised residential placements that provide ongoing assistance and access to as-needed specialised therapies or treatments. The modular house project offers 5 size variants of the objects, namely XS, S, M, L, and XL with alterations of both pitched and flat roof, as can be seen in Fig. 1. We chose the type L for this study because it shows two types of apartments and two floors, so it presents majority of aspects of the proposed design. The selected model project is located on a very narrow plot of land, which is typical for the Slovak rural environment. The width of the plot in this case was less than 14 metres. The architectural design is shown in Fig. 2.

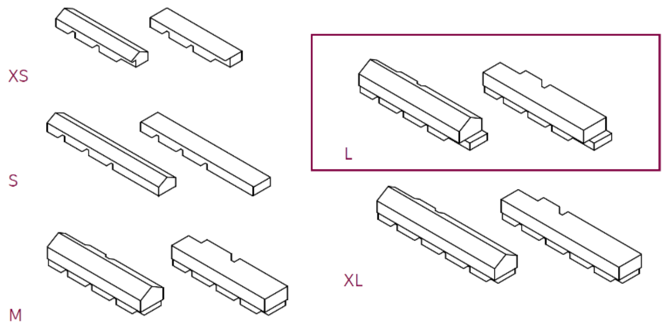

Fig. 1. Size variants of the model building – Type B – Family type house. (Source: Rollová, Bošková Filová, 2022)

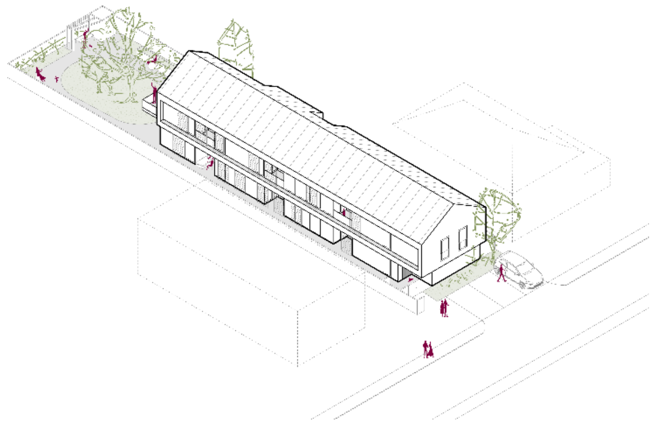

Fig. 2. Axonometric view of the model building – Type B – Family type house and its surroundings. (Source: Rollová, Bošková Filová, 2022)

The rooms in the large flat on the left can be single or double, they can be equipped and arranged in different ways according to the needs and wishes of the recipients, they are also suitable for the placement of adjustable beds accessible from three sides. The advantage is that the rooms can be merged and divided at any time and according to the needs without difficult structural modifications by means of a removable (non-masonry) partition. The bathrooms are large enough to allow for showering or bathing of persons in a lying position, or to leave enough space for a washing machine or other necessary equipment.

Robot manoeuvring in the house

In the premises of the selected model project Type B, size "L", the movement and functioning of assistive and butler robots was simulated. Our research investigated the functioning of robots in the selected model building, which, together with digital assistants of other kinds, could also provide people with some forms of social care support. We analysed the demands and needs of the robotic devices in performance, and the analysis was carried out using the "Pre-Occupancy Evaluation" method to evaluate a design prior to construction by simulating user behaviour or movement directly in the drawings. This helps verify the functioning of the existing design solution and the need for subsequent modifications to the design. In particular, the spatial requirements of the robots were verified, and it was investigated whether the layouts, room sizes and placement of built-in elements (e.g. in the bathroom) designed according to universal design principles were suitable for the movement of robots. Furthermore, it was examined whether the spaces are large enough for a person in a wheelchair and the assistive robots to function in parallel in each room under consideration. Appropriate placements of charging spots for both assistive and butler robots were also studied. Two selected robot models were researched, whose dimensions and the method of movement were taken into consideration during the investigation:

(1) Assistive Robot "RIBA II", short for Robot for Interactive Body Assistance, which was developed by the state research centre RIKEN (RIKEN, 2021) and Tokai Rubber Industries. RIBA will assist the care receiver in carrying or lifting the person or patient. For our research, the platform size (60 cm wide, 85 cm deep) and the method of locomotion on an omnidirectional wheeled chassis with a tall body (140 cm) and 2 arms are relevant (when arms are folded, the robot is 75 cm wide). The RIBA motor is quiet and thanks to the omnidirectional wheels it can move even in narrow spaces. Other features of the robot include voice and face recognition, as well as the ability to respond to voice commands or recognize co-workers and their location.

(2) Butler Robot "RELAY+S", a service robot, which was developed by Savioke, a Silicon Valley startup. Relay+S is one of 3 different payload configurations of the RELAY+ robot. We chose the Relay+S model, which contains open shelves that can be configured according to the customer's needs. The user interface communicates transparently by always disclosing robot activities. This is achieved through simple messages displayed on its screen and iconic eyes, which are meant to evoke empathy without overestimating its intelligence (Mucchiani, Sharma, Johnson, Sefcik, Vivio, Huang, Cacchione, Johnson, Rai, Canoso, Lau, Yimat, 2017). The robot can press a button to open a door, summon a lift, and so on which does not require investment in electronic communication with control units of these elements (Oitzman, 2021). The robot is on a circular omnidirectional chassis with a diameter of 51 cm.

These two robots are illustrated in Fig. 3.

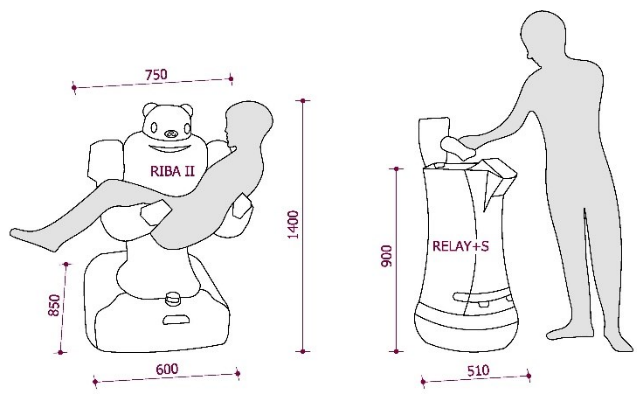

Fig. 3. Illustrations of the assistive robot RIBA II and butler robot RELAY+S. (Source: Bošková Filová, 2023)

RESEARCH RESULTS

The premises of the Type B – Family type house model building were analysed for the requirements and functioning of the Assistive Robot (route marked in red) and the Butler Robot (route marked in blue). The analysis is carried out sequentially according to a defined route that passes through all rooms. In each room, the role of the robot is defined and its space requirements and the required hardware are examined. Commands to the robots are given by humans – Care Receivers (CR) or Caregivers (CG).

The model building has integrated multiple Robotics and Automation Society (RAS) and Internet of Things (IoT) technologies with interfaces to enable user control (by CRs or CGs). Appropriately configured robots could help CGs to be more efficient in expertly supporting CRs and reduce their physical care requirements (such as lifting and carrying). However, the principle applies robots mainly perform tasks that CRs cannot do unassisted, supporting CRs to live independent lives. The following is a description of cooperation between humans and robots in the model project example. CRs can move around the apartment and the garden on their own, but also be accompanied by robots if they need their help or want their presence at a certain time.

Parking and entering – An autonomous robotic car (robo-car) will bring a CR with walking disabilities or a person in a wheelchair to the house. Assistive Robots will help in getting out of the car or transferring to a wheelchair, in traversing a ramp with a slight incline into the lobby. From the lobby, the human and robot can proceed to the 2nd floor or to one of the apartments on the 1st floor. The door of the apartment is unlocked by the CR themselves, e.g. by using their fingerprint, or opened by the robot using radio waves. The door opens automatically (it has a motor drive) when unlocked.

Apartment – In addition to human care staff, there are multiple robotic devices in the apartment that perform various activities based on commands from the CG or CR. The Assistive Robot assists with walking and transferring to a bed, sofa, bench, shower chair, or recliner or toilet, and can lift heavy loads. It also pushes a human on a bed out onto a terrace. The Butler Robot is used to carry various objects within the home and garden, for example, carrying food, drink, medicine. Cleaner Robots can vacuum and wash floors, wash windows, mow the lawn, etc. If needed, a social "Entertainer" Robot can also function in the apartment, with capacity such as talking to the CR, playing [e.g. games or music] and so on. Robotic devices will help evacuate the building if necessary.

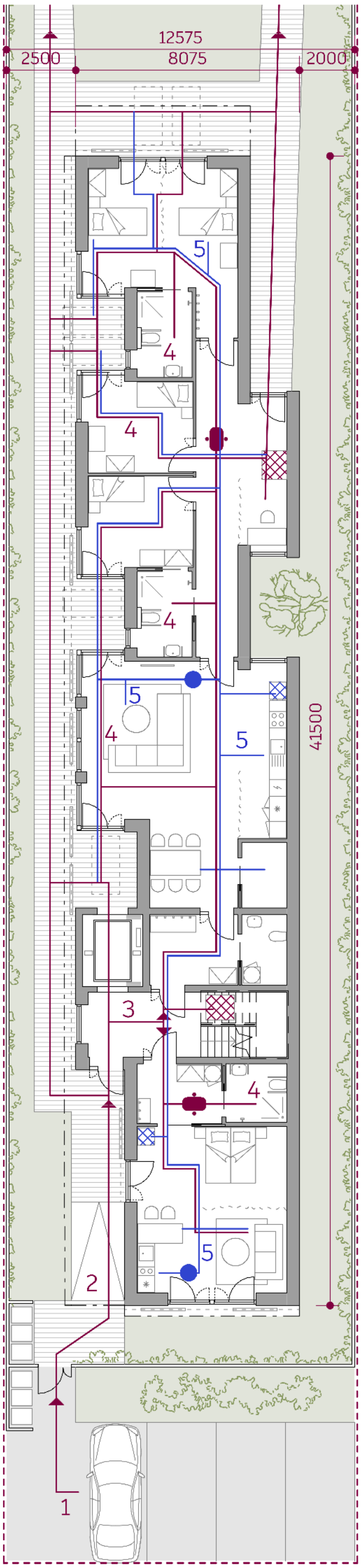

Fig. 4. Floor plan of the 1st floor of the building – Type B – Family type house and its surroundings with marked robots' paths and charging spots:

1 – The Assistive Robot assists in getting out of or into the car or transferring to a wheelchair.

2 – The Assistive Robot assists in traversing a slightly inclined ramp into the lobby.

3 – The Assistive Robot assists in opening doors using radio waves, if people want or need it.

4 – The Assistive Robot assists in transferring from a wheelchair to the couch, toilet, shower bench, bed, etc. and vice versa.

5 – The Butler Robot brings desired beverages, food, medicine, pillows, blankets, towels, remote controls, books etc.

(Source: Rollová, Bošková Filová, 2023)

Living Room and Kitchen – the CG prepares food, puts food onto plates and places them on Butler Robot, the CG gives orders for food delivery. The robot will take food to rooms if requested by the CR. Then the Butler Robot will bring the used dishes back to the kitchen. The CR chooses whether to eat in the room, at the dining table in the kitchen, or in the patio with other household members. The Assistive Robot can help transport the CR from the room to the dining room, or to the patio. If assistance is needed when walking, the CR can walk alone with the support of the robot (a standard mobile robot with handles at the back or a horseshoe-shaped robot with handles at the front). If the CR is immobile, the robot can help, for example, to push the CR on the bed into the common room or onto the terrace. The robot helps to transport a person in a bed or wheelchair to the living room, and helps to transfer to the couch.

Bathroom – the Assistive Robot brings or carries the CR to the bathroom, helps them to get on the toilet or on the shower chair and assists the CG in wet activities (robots cannot yet be used, for example, for showering). After drying, the robot again carries and transports the person as necessary.

Bedroom – the Assistive Robot performs simple tasks, assists in getting up and down, getting dressed, it assists a person in a wheelchair getting into bed. The Butler Robot brings the required items such as beverages, medications, the remote control, pillow, book, etc. If needed it can assist with eating (feeding) or monitor the current health status of the CR.

Doors – In addition to manipulating objects, robot's hands may also be used for opening and closing doors. However, it should be clearly stated that for the robot the operation of opening and closing of a standard door is not straightforward due to the need to coordinate the movement of the chassis, hand and of the gripper when opening the door, especially towards itself. In this sense, there is a requirement of the application of non-contact operated motorised doors, preferably of the sliding type. With a door of this type, the robot would only communicate via radio waves (either by command via a central system building or based on the NFR technology) and would not come into physical contact with them. The butler robot can also press buttons, such as the motorised door opener button.

The motion paths of the Assistive Robots and Butler Robots and their charging stations are indicated in Fig. 4.

DISCUSSION

The integration of robots into the manufacturing process is now commonplace and the use of robots in health and social care is probably the near future. Robots should not be seen as a technology that takes away people's jobs, but as intelligent technology that can work with humans, to be a tool to carry out difficult or routine tasks, for example, to supplement the labour market where there is a shortage of workers. In our research, the aim was to investigate how humans and robots can use a shared space and perform model tasks together. There is a need to distinguish which processes in human care remain more efficient when done by humans and which could be replaced by robots.

In our research, we analysed several robot models that are constantly evolving. For research purposes, information about the way the assistive robot moves, the size of the chassis and the necessary size of their manoeuvring space was particularly important. The RIBA II robot fulfilled the basic requirements. The size of the RIBA II chassis, which is derived from the size of the payload weight, is dimensionally appropriate and it will probably not be possible to develop an assistive robot with a smaller chassis in the future. We envisage that assistive robots will be able to perform more tasks in the future than it is today. In contrast, a butler robot may have a smaller chassis because it does not work with heavy loads. The service robot RELAY+S was chosen mainly because of its functionalities. The location for contact charger spaces in the model home was investigated. We account for the fact that there will be two robots of each type in the apartment, one of which is working at a given moment and the other one is being charged, so that there will always be one available whenever needed.

We compare the space requirements in terms of accessibility for people using wheelchairs and accessibility for robots. The major problems associated with the robot operation in the model project are summarised. In the selected model project, the requirements for bed mobility were taken into account in the design of spaces and doors. Thus, the bi-fold doors can be opened to a width of 120 cm if required. The more frequently used, wider door leaf is 90 cm wide, which is suitable not only for people in wheelchairs but also for robots. The manoeuvring space of a person in a mechanical wheelchair has a diameter (Ø) of 150 cm, which is significantly more than the assessed robots need. This circle must be planned around objects which are being handled for example in front of a door, a table, a cupboard, or by a bed. The circle can interfere under some objects to some extent, like the sink, the table – where the person can put their knees. There are solutions also for the wardrobe or bed with using retreat space or completely free space underneath – where one's feet will fit, so that one can approach and reach this piece of furniture and the spaces within it more easily.

The Assistive Robot RIBA II can rotate around a point, hence the manoeuvring circle is Ø 110 cm. The circle can partially interfere above some objects, because the arms of the robot's body are the widest, so the lower part of the body, the platform touching the ground, is narrower, only 60 cm. Therefore, the robot can also be inserted into narrower spaces about 60 cm wide, but then it needs a sufficiently high free space, e.g. under the bed or toilet, in order to be able to turn into the working position (the 85 cm long part of the base will thus be inserted under the bed). The Butler Robot RELAY+S rotates around a point, so the manoeuvring circle is only Ø 51 cm.

The following are the main findings from the application of robots to the floor plan: The model building project, i. e. the Type B – Family type house, is largely suitable or adaptable for the purposes of robot movement and operation. We proposed several modifications to it to enable robots to manoeuvre and be used in all spaces as required. More fundamental modifications had to be made in the bathrooms. We took into account the requirements of people with the greatest need for assistance, for example people with muscular dystrophy who need assistance to be transferred from a wheelchair to a toilet or to a shower chair. Adjustments were necessary because the robot needs more space next to a toilet or a shower than a human assistant does when "operating".

The sanitary items (toilet, sink and shower) in the bathrooms were reorganised to allow access to the toilet bowl from two sides, while maintaining the dimensions of the bathrooms. In order for the assistive robot to assist with repositioning, it would be inserted on one side of the toilet bowl and a person in a wheelchair would be inserted on the other side. Of course, it is also possible to move the person frontally from the wheelchair to the toilet bowl and vice versa, but this is especially the case if the person is able to stand on their feet. In the larger apartment, in order to maintain the adaptability of the bathroom accessible from the corridor as well as from the room, a shower without a folding shower seat had to be designed. However, the functionality of the

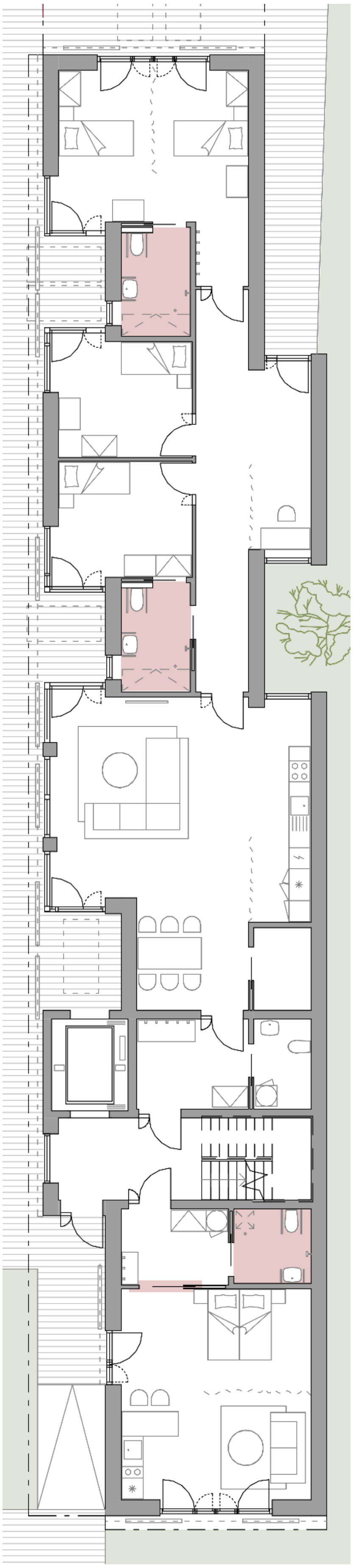

Fig. 5. Original floor plan design of the building – Type B – Family type house with the marking of spaces to be changed. (Source: Rollová, Bošková Filová, 2023)

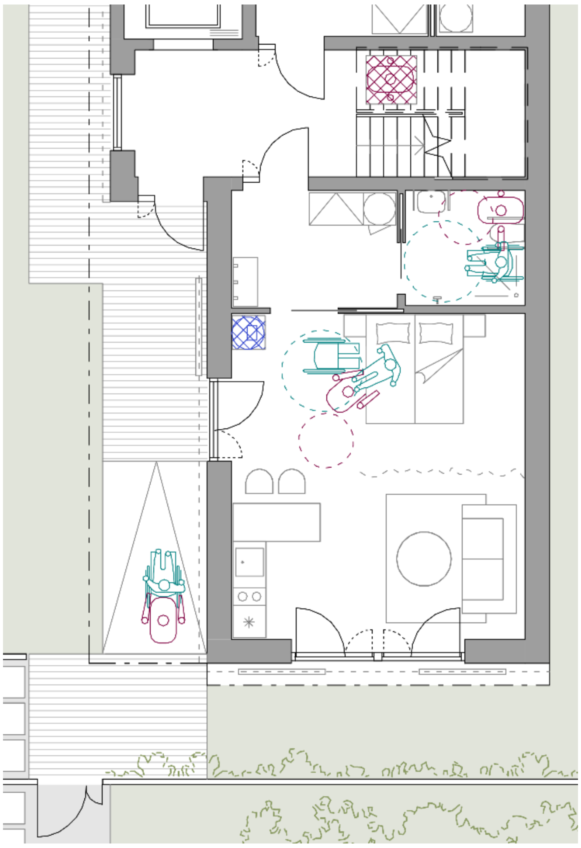

Fig. 6. Detail of the revised design of the building – Type B – Family type house. The entrance area and smaller flat. (Source: Rollová, Bošková Filová, 2023)

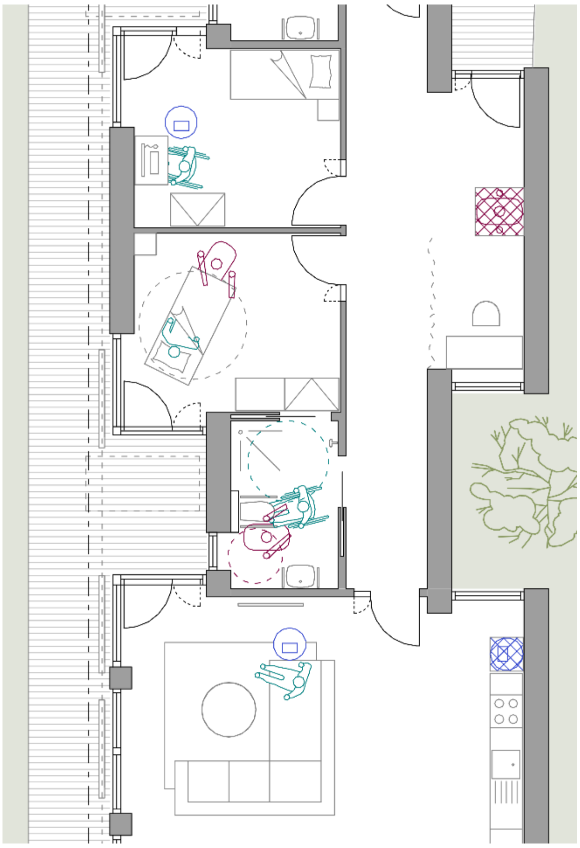

Fig. 7. Detail of the revised design of the building – Type B – Family type house. Part of the bigger flat. (Source: Rollová, Bošková Filová, 2023)

bathroom is not significantly reduced as a shower chair or a movable shower lounger can be used.

We design the charging spots separately for each type of robot to avoid collisions. In the smaller apartment it is difficult to find suitable charging points for both robots. Therefore, the larger assistive robot could be charged under the stair arm in a shared entrance area. The butler robot could be charged directly in the apartment, behind the entrance door. To this end, we have proposed a slight offset of the door from the original design to create a "bay" for parking this robot. Originally designed floor plan with marked areas that would need adjustments is in Fig. 5. Fig. 6 and 7 show parts of the floor plan with human-robot interactions in more detail.

CONCLUSION

Catering to all the unique needs of older people can be a difficult task for those providing personal care, especially as they have many other important responsibilities. Many older adults who are cared for feel boredom, illness, sadness, pain, and loneliness. Current research is looking at the extent to which robots could improve the quality of care. The environment also plays an important role in wellbeing. In this article, we reviewed research related to the functioning of assistive robots in a specialised facility (extra care home). In the future we plan to continue with this research, for example, we aim to investigate the movement and functioning of robots in a regular home so that older adults can be cared for in their own apartments. Research can also be focused on other building typologies (for example, for education and work) or compare the needs of humans according to the 7 principles of Universal Design with the requirements of robots. We see interdisciplinary research as crucial because assistive systems that can help people "age in place" in their own homes can increase the wellbeing and independence of older adults and people with disabilities, reduce the societal cost of care, and at the same time solve the problem of workforce shortages in the health and social care sector.

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