Demographic Change Robotics: Mechatronic Assisted Living and Integrated Robot Technology

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1 Introduction

Miniaturization and Downscale as basic forces of our technological development today increasingly enable a seamless integration of sensors, actors, microelectronic and mechatronic systems into buildings, building components and appliances. Furthermore, experts and masterminds, as for example Bill Gates, announce the era of service robotics and estimate that service robotics as part of assisted environments will undergo a similar fast and rigid development as the spread of personal computers in private and economic areas since the nineties. In 1961 Joe Engelberger already wondered, whether relating robotic technologies to only industrial applications makes any sense. "The biggest market will be service robots," (Englberger, 1989) asserted Engelberger, who started the industrial robotics era, when his firm (Unimation) delivered GM's first robot. Today, the application of robotics and distributed robotic sub-systems finally starts to extend into our home, office and town surroundings. This transformation, which has to be understood as a natural part of the evolution of robotics, will become visible especially when robots enter the field of service, assistance and care. We think that modern robotics assisting and servicing human beings will permeate into the "surroundings" of daily life and thus become an integral part of our built environment.

2 History: From Stand-Alone Robotics to Networked Service Towns

An analysis of the development of robotics being applied to provide services in the built environment shows a transition from stand-alone robotic devices to environments, which incorporate multiple robotic devices, appliances and services. From the 70s on, patient transportation robots, diagnostic and maintenance robots, humanoids and exoskeletons and edutainment and home service robots were developed as complex standalone devices, mainly designed to serve one specific task. Later on, during the 80s, robotic service devices appeared to connect and merge gradually with research fields as home automation and ubiquitous computing. The quite new research field urban robotics, which combines smart city research and robotics development to create robot supported urban life (see chapter 2.9), gives way to the assumption that this development will continue and transform our well known environment dramatically. This fusion started as prototypes of fully computerized buildings in Japan (e.g. TRON House 1, see chapter 2.6) and began to incorporate robotic devices as subsystems. Furthermore, the transition from stand-alone robotic devices to networked service environments is marked by a tendency towards dematerialization and distribution of complexity. In contrast to early service robots, complex service environments distribute tasks over several “smart” subsystems enhancing the efficiency of the total system and meanwhile reducing the complexity and size of the individual devices. Like Mark Wiser once envisioned the disappearance of visible computers as a reason of its fusion with everyday devices（Weiser & Seely-Brown, 1997）, we now may describe robotics, the new cutting-edge technology, as something, which starts to weave itself into the fabric of everyday life.

2.1 Transfer Robots

Robots for transferring are applied in the home environment to support people with motion disabilities (elderly, patients or disabled) and also to support their caregivers. Transferring is a basic activity of daily living, which means that it is accounted as fundamental for bathing, dressing, toileting, continence and feeding. Patient transport robots were in the focus of researchers and commercial developers since the beginnings of the service research in the 70s. Several types of transfer can be identified and various types of robots have been developed. Robots for lifting people from the bed, robotic wheelchairs and robotic walking frames are just a few basic examples to be named among a series of robotic patient transfer systems, which have been developed up to now.

Figure 1: from left to right: mechatronic system for lifting and transfer of people; intelligent wheelchair; robotic walking frame/rollator, robotic wheelchair from IRT (Prof. Shimoyama)

2.2 Diagnostics/ Maintenance Robots

Today robotic systems are not only developed for the construction of buildings but also for the economically important life span of buildings and other construction products. The first service robots for buildings and construction products had been developed in the end of the seventies / beginning of the eighties of the last century in Japan. These early service robots were used in the construction sector for inspection of nuclear power plants, exterior walls of high rise buildings and cleaning of high rise facades or glass roofs. In the nineties service robots were applied to civil engineering projects such as inspection of tunnels, railroad tracks and bridges（Bock, 2006）. Advances in the autonomous robotics research resulted in service robots for office logistics of files and security against intruders, gas leaks or fire hazards. Up to now diagnostics and maintenance robots were mainly treated as independent systems, yet, it can be expected that with the advance of building automation systems those servicing systems become an integral part of buildings in the future. In Europe researchers are already working on swarm robots acting as building integrated intelligent sun shading system（Yiannoudes, 2009）.

Figure 2: Left: Robot for diagnostics and automated exchange of façade elements, Kajima, Japan; Middle: Robot for façade diagnosis, Teisei, Japan, Right: Robot for multilayered painting, Tokyu

2.3 Humanoids and Wearable Robots

Humanoid robots are complex autonomous systems that can adapt to changes in the environment. Further appearance, function and motion capability are, in most cases, conceptually based on their equivalent in the human body. Androids not only interpret the human body's function but are designed to imitate human appearance and behavior. For both humanoids and androids service scenarios can easily be envisioned, yet, due to their technical complexity, real world applications are still rare. Exoskeletons state a contrary approach, combining the flexibility and intelligence of human beings with the speed and power of robotic systems in order to allow reducing the complexity of the robotic system. Exoskeletons can be seen as wearable robots extending existing human capabilities. Asian researchers and companies are leading forces in the development of those wearable robots. In 2007 the Japanese company Cyberdyne Inc. released the first commercially available Exoskeleton device.

Figure 3: Left: Humanoid robots are complex autonomous systems that can adapt to changes in the environment. Right: Exoskeletons state a contrary approach, combining the flexibility and intelligence of human beings with the speed and power of robotic systems in order to allow reducing the complexity of the robotic system.

2.4 Homemaking and Entertainment Robots

Especially in Japan, a multitude of so called Entertainment Robots have been developed and sold. Edutainment robots are designed to amuse, communicate, perform simple tasks in the household. Mitsubishi's Wakamura and Sony's Aibo for example had primarily been designed to communicate with household members / play music and not to provide care or household services. Yet, as the upkeep of social interaction increasingly becomes an integral part of care strategies, the taking over of entertainment and communication tasks by robots is envisioned by researchers and developers. Furthermore, Homemaking Robots are robots which take over simple tasks as cleaning, transporting of objects or informing about intruders or the pets' well-being. Often robots performing tasks in the household contain elements of both entertainment and homemaking robots.

Figure 4: Left to Right: Wakamura acting in a home environment, Homemaking Robot, Cleaning Robot, Home Surveillance Robot. Often robots performing tasks in the household contain elements of both entertainment and homemaking robots.

2.5 Automated Lift Systems

A multitude of lift systems has been developed to support essential activities of daily living in kitchen, bath, sleeping/dressing area, staircase area and working place. Lift systems are applied in the kitchen to move kitchen cabinets, workplates or appliances into an ergonomically demanded working position of any individual person. Similarly, lift systems are applied in the bathroom to move washstands into the necessary heights for disabled so they are able to perform basic washing and hygiene activities. Toilet lifts lift people to / from the toilet and another type of lifts helps people entering the bathtub. Furthermore, lift systems are applied to move clothes rails, so that disabled persons sitting in wheelchairs are able to utilize them thus being able to perform basic dressing activities. Moreover, stair lifts increasingly become popular and affordable. In face of the integration of more and more sensors in the home environment, proactive and automated control scenarios facilitating the ease of use of lift systems are now developed by researchers.

2.6 Home Automation

Japanese companies started with research and development of Home Automation systems already in the 70s. Home Automation Systems were developed by most of the well-known major electronic companies, such as Sanyo Denki (Shains) or Sharp (Home Terminal System, House Info System, Home Bus System). Already early processes included various functions: fire alarm, gas leakage alarm, oxygen shortage alarm, electric lock, burglar alarm, emergency alarm, earthquake alarm, guest monitor at door, interphone between rooms, door phone, power control, HVAC control and control of water level and temperature of bathtub. Today, Home Automation Systems become more and more modular, flexible and extendable. The Mitsubishi Melon HA System for example consists of an "inhouse information system", serving as a platform, which could be complemented by certain upgrade modules, such as the “household control system”, the “lifestyle information utilization system”, “house keeping”, “home management” and “life culture” modules. Furthermore, there is “fire and crime prevention”, “energy control”, “environmental and equipment control”, “data communications”, “health care”, “education and training”, “business and culture” and “hobbies and entertainment” modules are available for the same system（Bock et al., 2007）.

Figure 5: Left: Lift System for moving kitchen cabinets in an individually demanded position. Middle: stair lift able to move people in their wheelchairs Right: automatically bath/lavatory element.

2.7 iTRON Operating System (TRON House 1)

T-Engine and ITRON Operating System were components of a real-time operating system developed within the fifth computer generation programme ICOT by Prof. Ken Sakamura. The goal of the project was to create the technological basis for a computerbased society in the 21st century. Subsequently, the “TRON Intelligent house” (Tron House 1) was one of many TRON application projects conducted. The core of the concept was the symbiotic fusion of living environment, humans, computers and robots. It was completed in 1989 in Nishi Azabu and it was the most computerized building at that time with 380 computers interconnected via the T-Engine and iTRON operating system（Want, 2010）. While these modules were able to control every window and door, television, security system and even kitchen appliances, the building itself was made of traditional Japanese wood construction thus incorporating the new technology in a seamless way.

Figure 6: Left: Homemaking Robot leaving integrated robot house with recharge station in TRON House 1; Right: Designs seamlessly integrating technology in various home scenarios

2.8 Ubiquitous Communication (TRON House 2)

Recently Prof. Ken Sakamura designed and developed, in cooperation with Toyota Home, a new intelligent home, based on TRON and other leading edge technologies. The house is called "Toyota Dream House PAPI." It is a new intelligent home and was created to reflect the all-purpose computing technologies that will be available for intelligent home construction by the year 2010. The main objective of this project was to create and realize an environment-friendly, energy-saving, intelligent house design, in which the latest network computing technologies, developed by the T-Engine project, could be tested and developed further. The Ubiquitous Communicator (Human Machine Interface) identifies people moving through the computerized living space and their personal preferences can be recognized (Shimizu, 2005). Additionally, the whole building consists of units almost completely prefabricated by Toyota Home (on a moving production line).

Figure 7: Toyota PAPI Dream House, a cooperative project of Toyota Home and Toyota Motor Cooperation integrating technologies from both fields. The prototype of a fully computerized building was built upon the basis of Toyota Homes steel frame units. Toyota Home is modularizing buildings and prefabricates them completely by means of the Toyota Production System in a automated factory. The prefabrication of intelligent buildings is likely to reduce costs of smart environments dramatically.

2.9 Urban Robotics – Networked Service Buildings and Service Towns

Urban robotics is a research field situated between smart/sensible city research and robotics research. It's goal is to develop cutting-edge technologies as well as application scenarios for urban life, supported by robotic devices. The research field is pioneered by T. Hasegawa and his Town Management System (Murakami et al., 2008) enabling robots to outsource complexity to sensors and vision systems distributed in the city environment. Other interesting impulses in this research field are coming from research on smart cars and e-Goverment. Furthermore, NASA accounts controlled traffic systems and smart grid energy systems as so called "Immobile Robots" (Williams & Nayak, 1996). Also to mention in this context are the experiments conducted the Waseda Universitie's Wabot-House Institute (Sugano, 2008) led by Prof. Sugano. In the Wabot House buildings researchers from various backgrounds (architects, electrical engineers, psychologists etc.) are analysing the interdependencies and impacts of Humans, Robots and Environments on each other. Further the RoboCup@Home Initiative (Robo, 2011) aims to develop service and assistive robot technology with high relevance for future personal domestic applications.

Figure 8: The Robot Town enables robots to execute various tasks for ordinary human life by creating an interior and exterior environment well structured in informative way for robots and service systems. T. Hasegawa, Kyushu University

3 Integrated Service Robotics - Challenges

The next generation of robots will work in the direct operating range of human beings in order to achieve an extended stay of elderly people in an appropriate and with assistive technologies equipped home environment. Therefore, Robotic systems of the next decade will rather be “assistants” (EUROP, 2009), helping humans, disabled or caregivers to perform complex tasks, than fully autonomous systems. New interaction concepts, numerous concepts for lightweight robots, integrated force-torque sensors and teaching systems are therefore now developed by robotic companies around the world. Furthermore, the next generation of robots is designed to cooperate with each other in order to perform tasks in dynamically changing and flexible groups of intelligent devices. This will mainly be done by distributing processes and tasks over several devices and robots. Moreover, robots will increasingly be able to receive information of environmentally embedded Microsystems technology and sources as sensors, actuators and other microelectronic systems distributed in the environment. Long-term strategies even aim at globally distributed robotic cooperating systems, which could be part of decentralized and locally-based small scale networks (EUROP, 2009). This integration of robots with the environment leads to an ecology of sub-systems, where multiple assistance technologies, architectural measures, professional care givers, relatives and other care services are integral part of the robotic service system. This transformation is accompanied by challenges that have to be addressed by researchers and developers to guarantee a successful deployment of integrated service robotics.

3.1 Geriatric and Medical Challenges

The geriatric profile of elderly people in general can be specified by a so called “multi-morbidity” (Van den Acker, 1998), which is defined as the co-existence of two or more chronic conditions. Some of those requirements can be met with higher efficiency by “passive” systems (architecture, design, barrier free concepts, etc.), some by “active” systems (pervasive health technologies: micro systems technology, sensors, actors, integrated robotic systems, information technology). A carefully chosen combination of both passive and active systems would enhance the ability of environments to holistically address geriatric challenges significantly. Thus multi-dimensional component systems which can be customized and even personalized to specific multidimensional needs are gradually becoming a basic requirement.

3.2 Personalization Challenges

The sustainable transformation of existing “low-tech”, ordinary, homes into assistive technology enhanced home environments suitable for elderly people implicates several challenges concerning design and overall product architectures. Firstly, it is important to introduce hierarchical modularity or platform strategies cutting cross all related disciplines so that various assistive technologies or modules can be customized to a specific use case and further be exchanged or extended to meet the variety of possible use cases, even changing over time (Linner & Bock, 2009). The individual modules of the system have to be pre-configurable, easy to install and have to integrate an existing, presumably non-pervasive computing home. Maintenance, for care givers and receivers, has to be addressed by a designed-in serviceability. Secondly, the distribution and arrangement of functionalities, as for example the kitchen, bath, sleeping and related appliances and technologies have to be considered.

3.3 Ubiquitos Computing Challenges

Assistive environments need to be flexible and versatile to cope with the dynamically changing requirements of their inhabitants and support them, especially when health- and age-related disabilities arise (Kranz et.al, 2010). Components of a service unit might be exchanged to reflect the change in the health status, and therefore a pervasive computing middleware system is required to be able to deal with this change. Our approach is presented at the example of a scale model in Sec. IV. While smart homes, such as the AwareHome (Kidd et al., 1999) and the Place Lab (Intille et al., 2006), have been subject to research, they exemplarily stand for the aim of equipping the whole building or apartment. Our approach allows incremental addition and replacement of modules and components, not requiring an effort comparable to the augmentation of a complete home. This allows costs, as major factor when investigating deployment scenarios with real homes, to be kept within much lower boundaries, and it allows extension, if necessary.

3.4 Challenges in Middleware Design

Different middleware systems, such as GAIA (Roman et al., 2002) and MundoCore (Aitenbichler et al., 2007) have been proposed and used in the relatively young research field of pervasive and ubiquitous computing. The challenges of distributed multimodal information processing, connecting heterogeneous input and output technologies, have very different demands towards middleware systems. Unfortunately, reuse and development in our domain is usually limited to the initial developers of a respective middleware and no community evolved to pursue the ambitious goal of a unified middleware yet (Kranz et.al, 2010). Therefore, existing systems, were not being designed to have a long life cycle and to allow future inclusion of demands and upcoming technologies. This is why we consider the middleware to be an extremely important issue concerning deployable and working systems.

3.5 Social and Cultural challenges

In Japan pervasive technologies and especially service robotics have been seen as basic and natural elements in addressing the problem of the ageing society for a long time now. Therefore, today several robots are under advanced development, which can communicate (“PaPeRo”, *NEC*; “Mamuro”, *Center of IRT*), interact with human beings (“Emiew”, *Hitachi*; “Wakamura”, *Mitsubishi*) or perform complex service tasks (“Hospi”, *Matsushita*). Moreover, obvious robotic subsystems as robotic hands (“Tendy-one”, *Waseda University*), robotic suits (“HAL”, *Cyberdyne*) and robot control interfaces (“Brain Machine Interface”, *Honda*) are basic issues of both scientific and commercial research. A common characteristic of the Japanese efforts is that most service solutions are intentionally designed as “humanoid” or “mobile” systems and they are widely accepted and demanded by care receivers as well as care givers. Yet in Europe a different strategy is necessary for introducing high-tech based service, health or rehabilitation technology successfully, such as optically “visible” and obvious robotic systems are strongly related to production and "dull, dirty and dangerous" tasks. Therefore Demografic Change Robotics have distinctively to be designed as seamless "Immobile Robots", distributed and integrated into the service environment as invisible and highly customizable companions supporting health- and age-related disabilities.

4 Design of Robotic Service Processes based on Geriatric Assessment

Based on the fact that the society is exposed to a demographic change, long-term changes of the surroundings become unavoidable. These concern, above all, the optimized adaptation of the living environment to everyday courses of action and activity. Every person depends on activities as bathing, dressing, toileting, transferring, continence and feeding. For young people as well as for aging people with disabilities, the environment becomes a place where these basic activities of daily living finally have to be supported in a process like manner. To be able to describe, modify and support sub-actions and processes, which have a direct implication on the ability to perform those Activities of Daily Living (ADLs) and thus the ability of an elderly persons to live at home, restrictions and disabilities first have to be diagnosed (4.1) and a geriatric assessment of the skills and competencies of the elderly person has to be done (4.2). Diagnosis of restrictions and disabilities, geriatric assessment and the analysis of the ability to perform various Activities of Daily Living, allow that subsequently care strategy, support actions, sets of assistance technologies and distinct robotic devices can be deployed (4.3) to support a geriatric use case. Finally, based on these outcomes, service processes can be designed and optimized (4.4) by the systemic and integrated organization of assistance technologies, architectonic measures, professional care givers and robotic devices in the environment.

4.1 Restrictions and Disabilities

The health restrictions of older growing people can be divided into the following groups（Cavanaugh, 1999）:

a. *Sensorial restrictions:* Lack of eyesight, Lack of hearing ability, Limited olfactory organ
b. *Cognitive restrictions:* Losses of memory, Problems with speaking and concentration
c. *Motoric restrictions:* Lack of body mobility, Lack of skill, Lack of coordination
d. *Somatic restrictions:* Physical and organic complaints
e. *Social restrictions:* Lack of communication ability, Lack of motivation, Lack of personal hygiene
f. *Psychological restrictions:* Timidity, Depressions

For each of the potential restrictions several approaches exist to mitigate the disability thus easing the everyday courses of action. Everyday life can be simplified, for example, for a person with a visual impairment (sensorial restriction) by route guidance, accessibility, high-contrast composition, good lighting and acoustics as well as by organization of functions and assistive robotics. With route guidance, a high-contrast composition and ambient and adaptive lighting, the everyday life can also be simplified for a person with concentration issues and commemorative loss (cognitive restriction). Additionally, one can help people with cognitive restrictions in everyday life by a combination of assistive subsystems.

4.2 Geriatric Assessment: Activities of Daily Living

In order to diagnose the above mentioned health restrictions and to determine the Activities of Daily Living (ADLs) and the instrumental Activities of Daily Living (iADLs), various Geriatric Assessment methods have been developed（Gallo, 2000）. ADLs refer to basic tasks as bathing, dressing, toileting, transferring, continence and feeding, whereas iADLs describe sub-tasks that are necessary to accomplish those higher aims. The medical study group for the support of the geriatrics in Germany, for instance, worked out proposals and test procedures with the primary purpose to win new hints for the further therapy and care planning and for testing this on patients. Organ-medical, cognitive mental, psychic, social and surroundings-related problems and disabilities of older patients belong, among other things, to the potential restrictions. Immobility, incontinence, nutrition issues, confusion, decubitus and social problems are also in the center of related therapies and cure strategies. The flow of assessment is standardized as follows:

1) Screening by Lachs (General Assessment)
2) Barthel Index (Activities of Daily Living)
3) Timed Up and Go (Mobility)
4) Geriatric Depression Scale
5) MMSE (Mini-Mental State Evaluation)
6) Demtect (Dementia Detection)
7) Clock Sign Test (Mental State)
8) MNA (Mini Nutritional Assessment)

The first assessment test (Screening by Lachs) serves almost solely for the identification of geriatric patients. It offers the basis for the choice of other assessment procedures and contains aspects and indicators, which a doctor should consider during the therapy. The second procedure concerns an already widespread standard procedure for the appraisal of everyday activities and for the assessment of rehabilitation processes. Thereby, 10 criteria, as for example climbing the stairs, dressing and lining, food or washing are valued with 5, 10 and 15 points. The sum of the values lies between 0 and 100, the lower the point value is, the more nursing-needy is the person. The third procedure assesses the mobility of the patients. Do they, for instance, succeed in the following expiry – rising of a chair, walking a three meter distance, returning and sitting down – in less than 10 seconds, it is assumed that patients can move without limitation. If the patient needs more than 20 seconds for this performance, functional consequences on the mobility are assumed and further analyzed. If more than 30 seconds are needed for the performance, a support and care strategy should be considered. Furthermore, the Geriatric Depression Scale, the fourth procedure, concerns the emotional needs of the person and tests the level of contentment of the patients with possible hints concerning depressions. To be able to judge cognitive restrictions, certain basic conditions are required to not falsify the test result. A quiet and undisturbed atmosphere, encouragement of the patient through positive feedback and avoidance of negative statements are prerequisites for a successful assessment of the depression scale. Further tests as MMSE and the DemTect check the patient's mental state and abilities. Similarly, the Clocks Sign Test gives information about the mental state and possible dementia. Finally the MNA assesses the patients concerning nutritional aspects. Geriatric Assessment is a highly interdisciplinary task requiring the cooperation of medical practitioners, professional caregivers, psychologists and sociologists.

4.3 Linking of Restrictions, Activities and Assistive Systems

Older people in particular often become not only affected by one „disturbance“ or illness, but often several „disturbances“ at the same time. The following graphic (Figure 9, left) illustrates, which disturbance areas can have an effect on people and their ability to perform various Activities of Daily Living. A concurrent consilience of different disturbances can strengthen single clinical pictures or/and generate completely new ones.

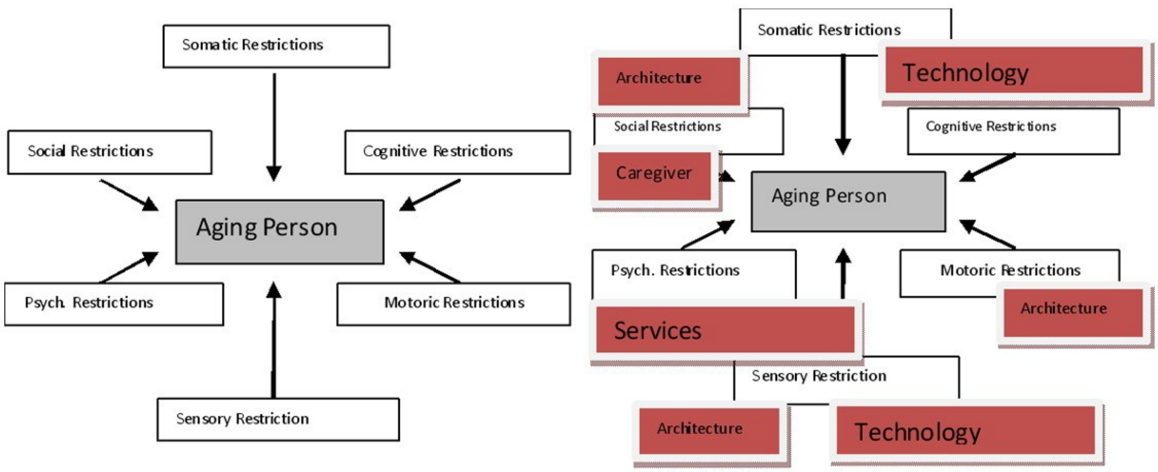

Figure 9: Left: fields in which reduction of activities potentially can take place. Right: service systems can be assigned to counterbalance an inability to perform certain Activities of Daily Living. The service systems in combination form an ecology of service system or a socio-technical system.

Category	Subsystems	Elements
Physical Classical **“passive” Sub-systems**	**Building structure**	Bearing structure: steel concrete, brickwork etc.
	Building infrastructure	Water pipes, cables, air circulation, energy generating modules etc.
	Building modules	Walls, columns, windows, doors, ceiling etc.
	Surfaces	Painting, stucco, plastering, textures etc.
Emerging **“active” Subsystems** Digital	**Mechatronic systems**	Wallcabinet lift, worktopunit lift, kitchen appliance lift, liftable toilet
	Embedded microsystems	Sensors, actors: senor floor, heat sensors etc., sensors for health conditions
	Wearable/ Implanted Devices	Sensors, actors in the body area, sensor shirts, implanted sensors/ actors
	Intelligent appliances	Controllable lights, refrigerator, washingmachine
	Interfaces	Touchscreens, voice mail, communication devices, mobilphones
	Robotics	e.g. robotic bed Panasonic
	Mobility Systems	Intelligent wheelchairs, Toyota i-swing, Toyota I-Unit, HAL Cyberdyne
	ICT Enabled Applications	IT platforms, monitoring/ tracking systems, Ambient Intelligence, Proactivity
	Physical & Digital services	Care service, supply with goods, supply with information, emergency alert/call etc.

Table 1: Systematic listing of „passive“ and „active“ subsystems which can be integrated in a robotic service environment as basis for the definition of a new language for defining complex health environments through integrated subsystems.

An analysis done by the authors of more than 100 technologies relevant for service environments（Linner et.al, 2011）has pointed out that most assistance systems are able to counteract one or maximum two of the above mentioned restrictions and disabilities. To be able to counteract multimorbidity and the often unpredictable appearance of several restrictions going along with it, residential surroundings must be constructed for encouraging a cooperation of different assistance technologies, architectonic measures, professional care givers, relatives and other care services. These service systems can be assigned to certain categories of potential disabilities in order to counterbalance an inability to perform certain Activities of Daily Living (Figure 9, right). The service systems in combination form then a complex ecology of service system or a socio-technical system. In order to use the full power and potential of rooms and other physical spaces for supporting the ability to perform various Activities of Daily Living, robotic service environments are based on a new language for defining complex health environments through integrated subsystems. Through a high degree of modularity, it would be even possible to dynamically integrate subsystems in order to react with the changes of demand and ability to perform Activities of Daily Living. The following table (Table 1) lists „passive“ and „active“ subsystems which can be integrated in a robotic service environment to assist various use cases.

4.4 Process-Oriented Design of Service Environments

In service environments, assistance technologies, architectonic measures, professional care givers, relatives and other care services form an ecology of sub-systems, which has the aim to support the ability of performing the Activities of Daily Living as described. In order to organize this ecology of subsystems and to create process-optimized residential service surroundings, proven strategies for process design and process optimization can be applied. Firstly, fundamental principles of designing, managing and optimizing socio-technical system can be transferred and applied to service environments and the ecology of subsystems (4.4.1). Secondly, living environments in general and service environments in particular can be described and organized as “living machines”, which are designed to allow optimized living processes (4.4.2).

4.4.1 Taylor and Ford

Frederick W. Taylor worked on the scientific pervasion of working processes. By the consideration of processes in working surroundings, formed by the interplay of persons, materials, tools and machines (process analysis), and a following reorganization (process modification) according to a „Best Way“（Taylor, 1911）principle, he transformed the view on complex socio-technical systems. Instead of focusing on single parameters (surrounding, person, expiry, tool, raw material), he was especially interested in the behavior and productivity of the overall system. This can be shown very well by the slide rule for shooting for example, which Taylor had developed to be able to determine the consequences of different influencing variables on a process unit (task, tool type, rotating speed). Later on Henry Ford was able to build upon the scientific results of Taylor and transferred these attempts of systemic and scientific management to highly mechanized manufacturing systems. Like Taylor, Ford observed the overall system and saw the people as an integral sub-unit of this system（Ford, 1926）. Taylor and Ford determined not only work routines or mechanical, technical processes, but their aim was rather to understand the complex interaction of human, machine, time, auxiliary supplies and raw materials to be able to achieve process improvements by their reorganization. With this they also created the foundation for the development of socio-technical systems or of systems, in which human and machine interoperate synergistically.

4.4.2 Efficiency in Home Management: “Frankfurt Kitchen”

The Frankfurt kitchen (Figure 10) was developed to enable efficient flow of work. The Ideas of Taylorism strongly influenced the inventor of the Frankfurt kitchen, Margarete Schütte-Lihotzky. Inspired by Christine Frederick’s（Frederick, 1913）efficiency studies in home management and her publications on efficient and functionality-oriented housekeeping, Schütte-Lihotzky finally transferred the principles of Taylorism and standardization into the German kitchen. The Frankfurt kitchen states an example for a kitchen, in which the order and the form of elements and sub-systems as well as the planned interactions taking place in the environment have arisen from the scientific analysis of processes and activities. Furthermore, it shows how process improvements can be scientifically deployed in the residential sphere. In comparison to a conventional kitchen it is very well recognizable that in the “Frankfurt Kitchen”, the amount of movements and work steps needed to perform certain activities, that are related to the higher level aims as cooking or preparing food, had clearly been reduced. Figure 10 (right side) shows that through reorganization of work setting and appliances, the activities of daily living can be performed with less effort and even within less space. Similar to the Frankfurt kitchen, complex and technology supported home or service environments and thus ecologies of assistance technologies (including robotics), architectonic measures, professional care givers, relatives and other care services have to be studied, organized, managed and optimized so that activities of daily living as well as care services can be performed efficiently.

Figure 10: left: The Frankfurt kitchen transferred the principles of scientific management (Taylorism) into the German kitchen; it was developed to enable efficient flow of work on less space. Through application of Taylor’s principles the amount of movements and work steps needed to perform certain activities that are related to the higher level goals as cooking or preparing food had clearly been reduced.

The outlined process oriented design strategies provide important starting points for the development of complex service environments. With the focus on Activities of Daily Living, a process-oriented organization or re-organization also outperforms the traditional typological organization of living environments and thus the classical separation of rooms and functions (living, working, cooking, sleeping). Future service environments will be characterized by functionality, standardization, process-oriented designs and process-oriented arrangements incorporating the mentioned ecology of subsystems and supporting the implementation of assistance technologies and service robotics in the home environment. A high degree of functionality, standardization and process orientation is predestined to support the deployment of automation and robotic devices in home service environments.

5 Customization of and Integration of Robotics into Personal Health Environments

The Combination of Mass Customization Strategies with the integration of modular sensor-actor systems to build up flexible Personal Health Environments is a field which is currently pioneered by the authors. To guarantee a sustainable implementation of health technologies and assistive robotics in the home or service environments, a concept of scalable, highly modular and customizable service units has been derived from the challenges discussed in chapter two and the design strategy for robotic service processes outlined in chapter three. Robotic service units are designed as a "compact" alternative to fully networked homes and houses. Recently designed German prototypes of assistive homes as "Haus der Gegenwart" (eng: house of presence) (Microsoft, 2006) and "Haus der Zukunft" (eng: house of the future) (Telecom, 2006) are exemplarily equipped with a variety of networked pervasive technologies integrated by modern and "expensive" design. Both these homes act as demonstrator and as technology probe, supporting and facilitating discussion as does our scale model. Nevertheless, both approaches do not address topics as modularity or interoperability on physical or digital level. Those approaches would require a house, which is built from scratch or at least costly renovation. In contrast to the robotic service unit system, approaches presented by those prototypes do not allow gradual implementation, simplified "upgrading" or continuous customization of existing environments, which could be accounted as essential to deploy pervasive health environments, as discussed before. Non-German examples for assistive homes as the "House_n" (Larson, 2003) and the "Toyota PAPI House" (Shimizu, 2005) offer higher modularity achieved by modular and open architectural concepts, yet they do not use the potential of that approach and still require basic parts of the building and its infrastructure to be built from scratch. The scalability of both systems is restricted to newly built environments; they are also not explicitly designed for implementation into existing and naturally grown environments.

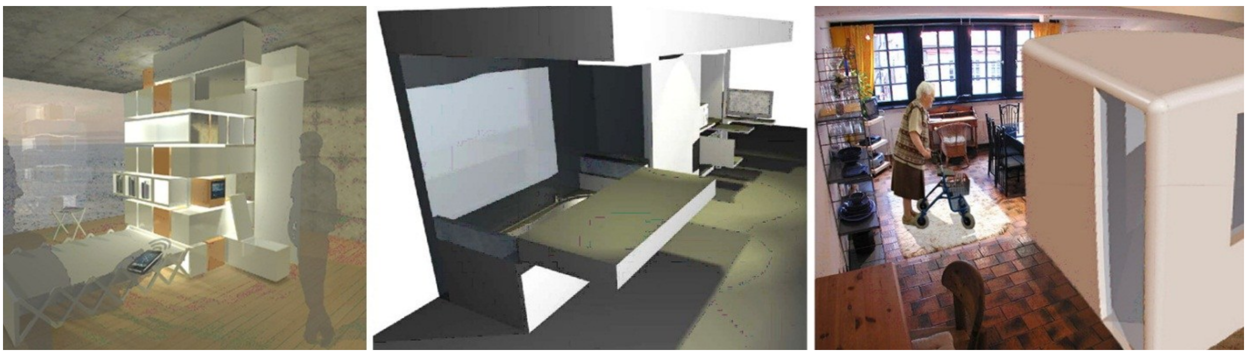

Figure 11: In order to meet different demands and disabilities and thus configurations of the living environment, three basic typologies of robotic service units have been developed. Left: Core Type Robotic Service Unit. Middle: Wall Type Robotic Service Unit. Right: Room-in-Room Type Robotic Service Units. The pictograms show how functions are organized through each type. (Linner et al., 2010)

The robotic service units, discussed and developed by the authors, on the contrary, addresses these issues, integrating assistance technologies through a hierarchically structured and highly scalable prefabricated component system able to be installed as an adaptive continuously changeable subsystem in existing low-tech homes. Further the units have been designed in respect of the challenges mentioned in section 3 and along with guidelines of designing of robotic service processes based on geriatric assessment outlined in section 4. In order to differently meet the demands of different use cases, possible disabilities and configurations of the living environment, three basic typologies have been developed (Figure 11) by the authors:

- **Core Type Robotic Service Unit:** The prefabricated Service Core is a typology that could be used to break up conventional room partitions and to create floating rooms around it. It is placed in the middle of a room, house or flat and organizes customized functions as kitchen, bath and/or sleeping circularly. Customers are free to choose from a pre-defined set of functionalities, smart appliances, sensors and interface systems to equip their Service Core in order to meet their preferences and assist their daily activities. All obligatory and compulsory system components are concentrated in the prefabricated core element reducing the complexity of Ambient Intelligent Environments to the core. The surrounding space thus could be designed, arranged and re-arranged freely and without complex renovation. The service core concept is mainly applicable to small and medium sized single-person apartments. The service core kit has been built up on a 36 x 36cm module size derived from balancing human scale with the smallest module size needed for integrating functionalities of daily life. All modules are including dedicated functions and are equipped with motors allowing them to back out from the core or backtrack into the core. The state of the modules and thus the functionalities organized around the core can be controlled by the user and/or by Ambient Intelligence.

- **Wall Type Robotic Service Unit:** prefabricated Service Wall melts usually separated systems as “wall” and “assistive furniture” into one system combining them with mechatronic sub-systems (26), sensors, actuators and ambient intelligence. The system (Fig.04) could be erected besides an existing walls or could be used to substitute walls within houses or condominiums. The Service Wall has been designed especially for people with mobility complaints and which are not or no longer able to move by themselves from one location to another and thus to perform actions as cooking, washing or other daily activity. The Service Wall assists in exactly those situations when mobility gets lost and helps handicapped people to be able to move to toilet, washing basin or kitchen by themselves where they can then perform specific daily tasks and thus keep up mental and physical activity. The wall itself is a modular and prefabricated kit providing basic living functions as sleeping, bath, kitchen and home office on compact and constraint space. The concept is currently developed further and prototyped by the authors in the collaborative F&E-Project LISA (LISA, 2011) with companies and other stakeholders.

- **Room-in-Room Type Robotic Service Unit:** The prefabricated *Service Room* is a unit which could be integrated into flats as a “room in room” system. With its standardized height of 235cm, it could be positioned in an apartment in an old building as well as in a newly built house. Similar to prefabricated bath or toilet-units for high rise buildings which have been used in building industry since the 70ies, the service room could be delivered to the site as modular kit or completed unit. The Service Room unit is designed for people with severe motor and cognitive disabilities. Within the constraints of the unit all functionalities and appliances which are needed to serve severely handicapped person to stay at home can be concentrated. Within the constraints of this compact unit a minimum of motion and/or movement is needed to perform daily tasks. Biosensors and a system that allows for telemedical Services make the room-in-Room Type service unit to a hospital at home.

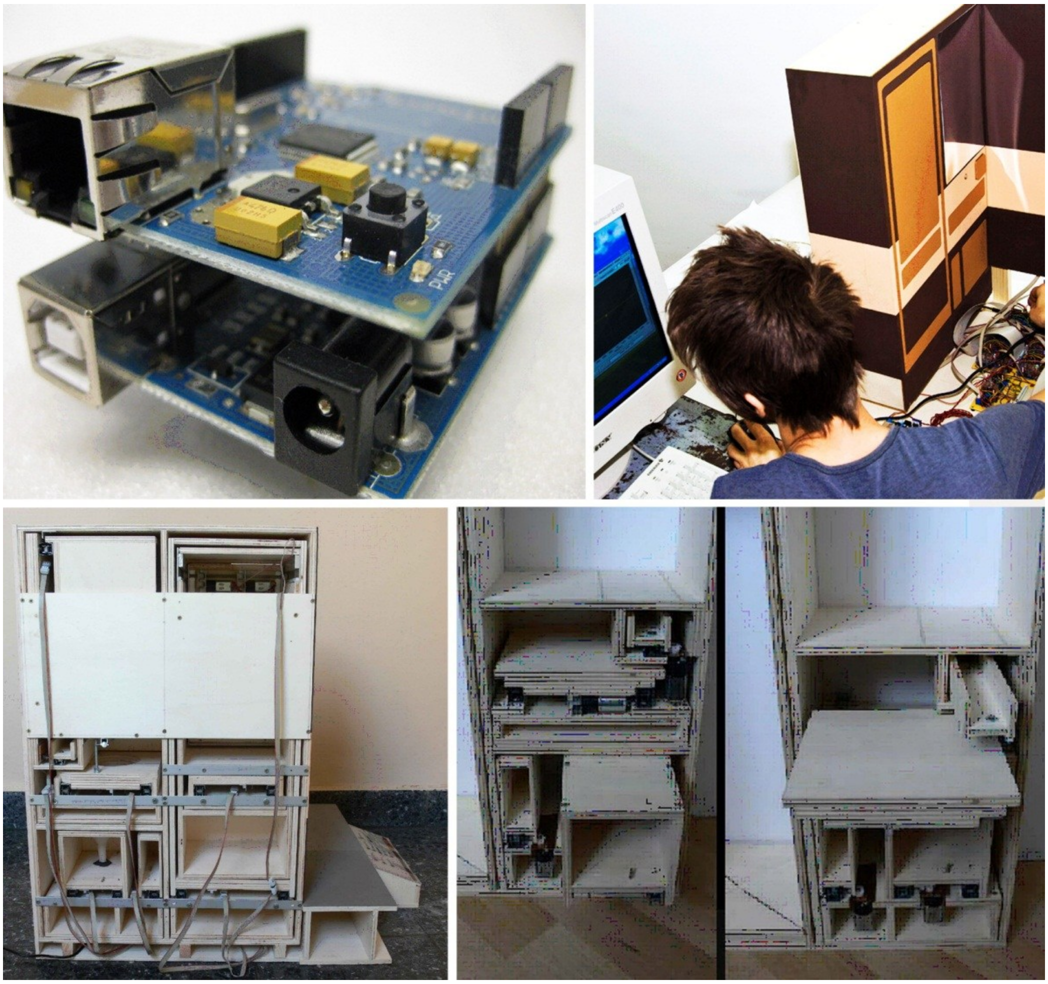

Figure 12: Fully functioning prototype model of a robotic service unit, Scale 1:4. The Service Unit "chassis" is customizable through modular and compatible sets of functionalities, smart appliances, sensors, actors and finishing designs. All functions can be automatically retracted into the core unit. The picture show experiments with mock-ups that were conducted to develop the modularity.

Furthermore, the robotic service unit, as a system in total including platform and compatible service functions has been designed as an invisible and immobile robotic system (Figure 12). The use case specific subsystems are not only networked and controllable but technology works seamlessly and to a high degree autonomously in the environment's background. The robotic service core makes use of the concept of distributing and embedding robotic systems into environments. Environments enriched with "sensor" and "actor" systems, given certain autonomy and able to control their complex internal functions, are considered as "ImmoBots": Immobile Robots (Roush, 2003). In general, those systems can cover networked building energy systems as well as power grids or reconfigurable traffic systems. Further systems as photocopiers, able to coordinate a multitude of internal subsystems with a model based programming approaches or whole cities equipped with smart subsystems, can be called "Immobile Robots". NASA also considers space vehicles and space stations equipped with various networked subsystems and intuitive and multimodal control interfaces as "ImmoBots"

（MCCandless et al., 2006）. A common characteristic of “ImmoBots” is that they are able to control their internal subsystems autonomously for achieving certain aims, reducing mental stress of human beings interacting with them. The concept of the robotic service core is taking up this approach of autonomous and mental load reducing self-control of complex networks of subsystems to support elderly people with case specific sets of sub-systems and assistive technologies in a home or service environment to perform basic Activities of Daily Living (ADLs) in an upgraded and highly efficient home environment.

6 Application Scenarios for Modern Service Robotics

To outline and visualize the transformations our surroundings will undergo through the permeation of robotic devices into everyday life, we present various studies on application scenarios for modern service robotics in this chapter. We account the systemic and interdisciplinary development of application scenarios as increasingly important means of intentionally challenging and guiding technological advancement.

6.1 Robotic Service Walls: Immobile Robots

The independent and care supported living in a conventionally designed and low-tech home is often unpleasant nowadays, and in many cases not suiting to counterbalance or the ease of disabilities and support Activities of Daily Living. Especially by entering a later stage of life, changes of habits and lifestyle occur and unforeseen disorders, multi-morbidity and disorder progresses often make existing houses or flats inapplicable for elderly inhabitants. In many cases, a re-configuration of the existing home or the implementation of various assistive technologies as modular component systems would be needed to meet multiple needs with multiple sets of technologies. Normally, the implementation of new technologies, sensors, actors, assistance devices and robotic sub-systems needed in a certain use case normally is a complex, costly and time consuming matter, often forcing elderly people to move to a new home, or to set aside the idea of being supported by advanced assistance technology. The approach of robotic service walls tries to simplify the integration of advanced assistance technologies into existing homes (Figure 13). The service wall is a compact, modular and customizable service entity, equipped with technology packages, bound together for supporting certain disabilities or sets of disabilities. The service wall thereby contains all service functions and assistance technologies, which do not have to be distributed over the whole flat. As only the service wall has to be installed in the home as a compact prefabricated and pre-configured module, cost and complexity of the rearrangement itself are minimized allowing for the investment into advanced assistance technologies. Robotic service walls make use of the concept of distributing and embedding various sub-systems into environments. Robotic service walls are able to control their complex internal functions and can be considered as Immobile Robots.

6.2 Robotic Furniture

Mechatronic systems, downscaled motors and lifting systems, integrated sensors and acorns in combination with new technologies for human-machine-interaction can be accounted as sub-systems of immobile robotic systems. If such sub-systems are integrated and merged with everyday artifacts as furniture, appliances and whole buildings, those artifacts tend to change both, functionality and appearance. Emerging technologies are not only transforming functionality, but also designs and forms of our environment, following the principle of “form follows function” (Sullivan, 1896), being discovered and scientifically explained by L. Sullivan already more than one hundred years before. The integration of robotic systems and sub-systems is likely to transform the appearance of our environment and everyday’s artifacts, similar as done by the implementation of new materials as steel or plastics once before. Figure 04 shows a study about an assistive kitchen, equipped with sensors and actors and with flexible and livable multilevel work planes. Those work planes can automatically be adjusted to working tasks, people’s height and ergonomic needs serving people and making cooking processes more efficient, especially for elderly people. Moreover, new interface and projection technologies make it possible that information is not any more restricted to a separate screen but can be distributed over the whole system, appearing on demand. Figure 14 shows that the whole kitchen system could be industrially fabricated as a modular kit. The study shows, by using a simple example, that, if the idea of integrating advanced assistance technology is worked out consequently, functionality and form of future artifacts as kitchens will distinctively be different in form than what we know as a today's kitchen (Bock & Linner, 2010).

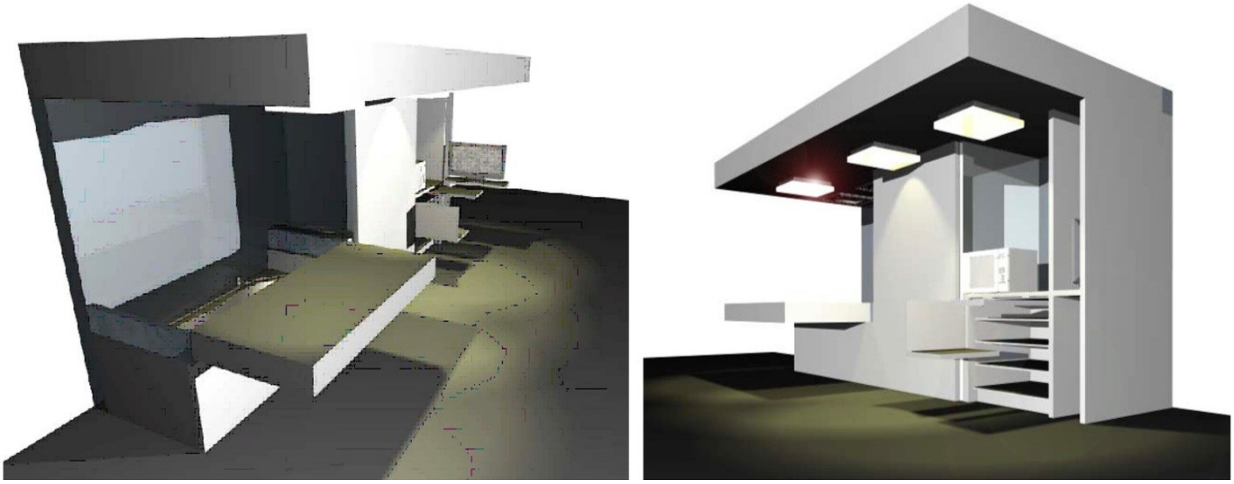

Figure 13: Robotic Service Wall supporting elderly people with multiple disabilities in a home or care environment. The Robotic Service Wall is a compact, modular and customizable service entity, equipped with technology packages supporting Activities of Daily Living (ADLs). As mentioned above, the concept is currently developed further and prototyped by the authors in the collaborative F&E-Project LISA (LISA, 2011) with companies and other stakeholders.

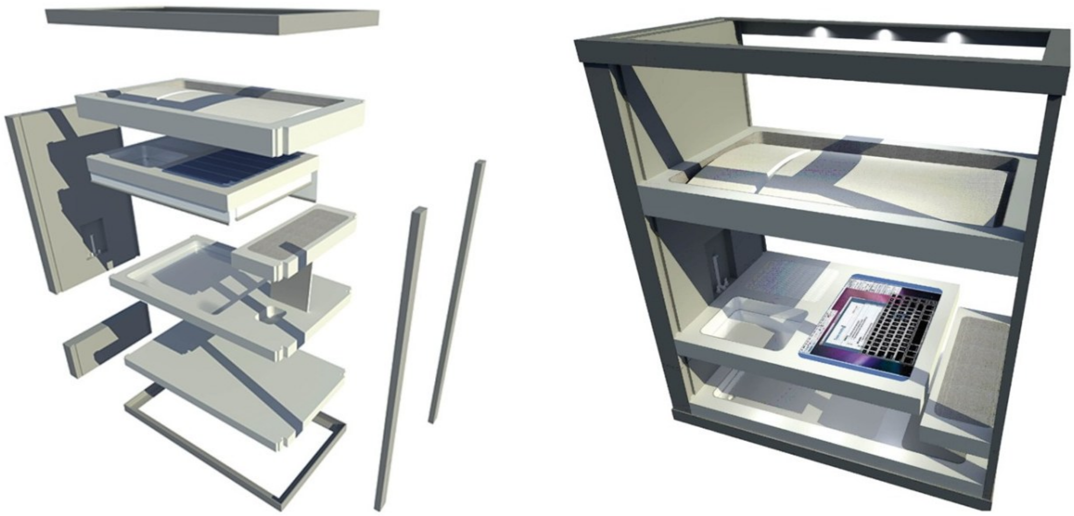

Figure 14: Modular and customizable robotic kitchen furniture. Given the principle of "form follows function" (Sullivan, 1896), modern robotics is likely to transform appearance and design of everyday artifacts.

A practical example how sensor-actor systems integrated into various types furniture can support daily activity and condition of health of persons is provided by the GEWOS R&D Project (GEWOS, 2011). GEWOS is a University-Industry collaborative project financed by the German ministry (Runtime: 2010-2013). Its objective is to upgrade furniture components with sensors and other mechatronic components in order to support a healthy, save and active life at home. Among the Partners also the Fraunhofer Institute for integrated circuits (section medical sensors) and EnOcean GmbH, a forerunner in energy harvesting and sensor applications. First target of the consortium is to develop a "Fitness Chair" which is measuring people's vital signs, makes those vital signs then transparent to the user and finally try's to activate the user to become more active (Figure 15), do sports and meet friends.

Figure 15: Sensor Chair developed within the authors' R&D Project GEWOS. The "Fitness Chair" is measuring people's vital signs, makes those vital signs then transparent to the user and finally try's to activate the user to become more active (Figure 16), do sports and meet friends.

Above that the chair provides an open server platform which allows doctors, physical therapists and other health professionals to develop custom services applications for the chair and its users. Companies as well as researchers are interested in bringing this solution to the market. In March 2011 it has even been covered by the German issue of Technology Review. The chair contains following systems:

- **EKG-Module:** Measuring heart rate variability
- **SPO2-Module:** Measuring blood pressure and oxygen saturation of the blood by infrared and special signal processing algorithms
- **Activity-Module:** Sensor system for analyzing the user's activity in proximity of the chair
- **Weight-Module:** Measuring weight and weight distribution on the chair
- **Data Platform with GUI:** Allows third parties (doctors, physical therapists and other health professionals) to develop custom services applications
- **Gaming Aspect:** Chair itself can be used as controller and training application to enhance the users' activity at home.

6.3 Robotic Care Environments

In the future, technological complexity will be shifted from the care robot to the environment and distributed among various intelligent subsystems. The future care robot is supporting care helpers or people in need. It will be complementary part of an intelligent care environment as well as sensors and actuators attached to doors, furniture, ceiling and so on, to enable an environment to support and take over robotic tasks（Bock & Linner, 2010）. The future care robot has the capability to cooperate with various su b-system components in it's surrounding, melting robot and environment to an integrated and efficiently working entity. Figure 16 shows the concept for a multi-joint robot as subsystem of a robotic care environment. The system has been developed by the authors for Synco GmbH, a German firm active in the professional care and health sector, which has recently patented the system and is now thinking about its produceability and market introduction. Some modules include adapters that allow the attachment of different tools and connectors in order to facilitate the nurse/ care helper aid with modular equipment. All elements of the care environment, from bed to bathtub, are designed as a complementary part of the robotic care environment (Figure 16) and have the capability to couple with the robot digitally and/or physically to perform certain tasks as an entity through plug and play interfaces.

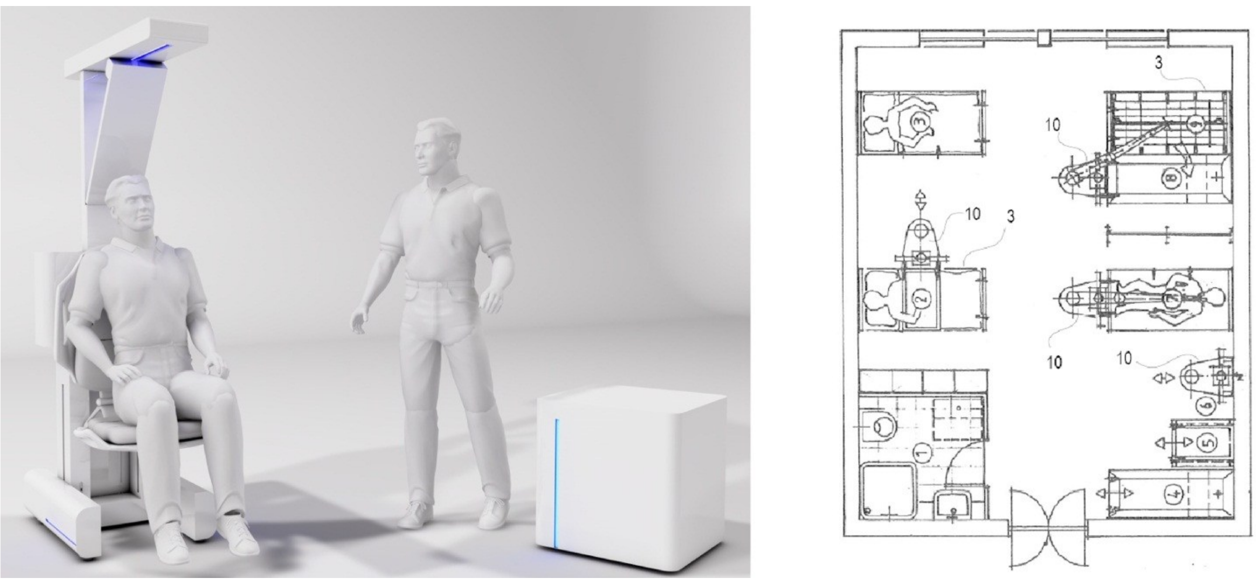

Figure 16: Visualization and layout of robotic nursing station supporting caregivers' tasks. In the future, technological complexity will be shifted from the care robot to the environment and distributed among various intelligent subsystems. Furthermore, caregiver and robots will form entity incorporation the advantages of both human beings and robotic systems.

Figure 16 also demonstrates the layout of a possible nursing station: Tablet storage (5), bathing area (1), four beds (3). The Nursing robots are performing different tasks, one is handing a patient a tablet (2), one is getting ready to move a patient (8) from the bed onto the netting (9) and one Nursing Robot (10) is charging its battery (6). The main idea in this scenario is to see robotic application and its surrounding environment as one organism built on cooperating and co-adapting subcomponents. In a robot supported nursing station various care robots can perform assistive tasks supported by intelligent subsystems and sub-components as for example bed, health care system, doors, toilet or shower being complementary elements of the whole system.

6.4 Mobility Supporting Robots

The authors also have been researching in the field of mobility supporting robots for several years together with students and researchers of various professional backgrounds (Architect, Designers, Electrical Engineers and Informatics). E-Move is a concept that has been developed by the authors' lab's mobility group recently. Also it has not been prototyped yet parts of the concept have been transferred into the GEWOS R&D project, one of the lab's biggest research projects mentioned above in section 6.3. E-Move helps to improve the quality of people's lives. It is strongly connected to today's issues and is designed to solve the problems of tomorrow. E-Move provides the ability to control one's own life, preserve self-respect, independence and maintain personal space, no matter the age group or health disability of the user (Figure 17). The system has three main components – a comfortable chair, a docking system and an electronic bracelet. Each is designed to match different people and to adapt to different situations in order to allow free movement both in private and social environments. The main aim of the system is the re-integration of people with health problems into society. This re-connection will not only ensure higher quality of life-existence but will also develop these societies in all aspects, both economically and humanely.

Figure 17: Modern Mobility Robots not only transfer persons but also foster a re-integration of users with disabilities and health problems back into society through allowing for interaction with other users, cars, buildings and the city.

6.5 Robotic Everyday Companion

Accompanying “ubiquitous” mobility concepts, as described in the former section, a next step in the evolution of robotic assistants might be the introduction of robotic companions. Similar to Toyotas Robotic wheelchair, which could be switched in a stand-by mode autonomously following its owner, robotic town companions could follow and assist with multiple activities in the town area as shopping, orientation, carrying of loads and/or guidance. Moreover, these robotic companions will not appear as typical technically looking or humanoid robots, but as simple and fancy artifacts, which are used by younger people as well as by the elderly. The overall design principle enables its use for care receivers. Similar to our smart phones today, robotic town companions might assist us also with location based services, and a multitude of downloadable applications making robotics a fancy and widely accepted assistance technology.

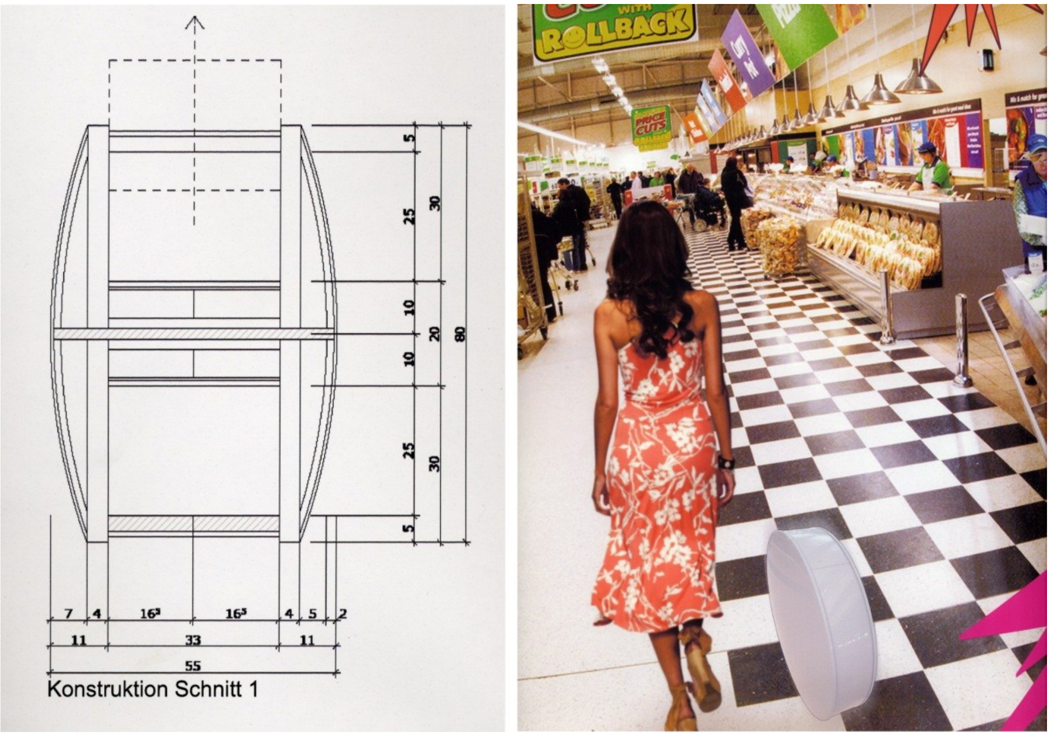

Figure 18: Robotic Shopping Assistant: robotic companions will not appear as typical technically looking or humanoid robots, but as simple and fancy artifacts which are used by younger people as well as by the elderly.

6.6 Robotic Buildings

The Service Units presented in the former section have been designed to reduce the complexity to a compact entity. Those units are representing an intermediary step. With on-going downscale and miniaturization on the one hand and extended performance of hardware, sensors, actuators, mechatronic systems and complex robotic systems on the other, whole buildings are likely to become “machines” or “robots” in the future. Those robotic buildings can integrate and cover networked building energy systems as well as power grids, reconfigurable traffic systems or complex and assistance technologies in one system. **Figure 19** shows a study on a robotic building which is able to consciously change its form and adapt to occupants, needs and environmental conditions (Bock et al., 2010). Reaching that level of complexity and interoperability of subsystems means that whole buildings could operate as proactive assistive system.

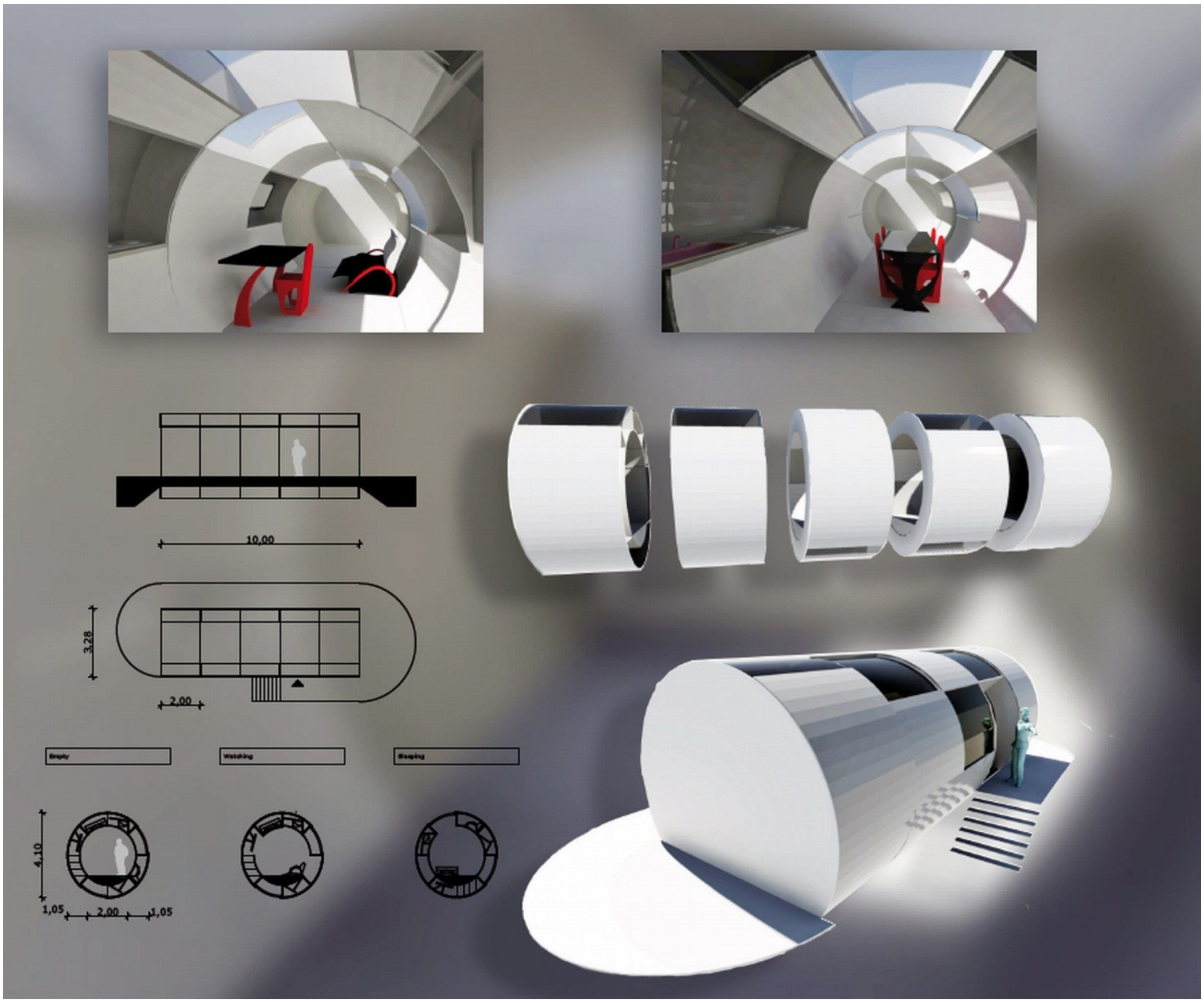

Figure 19: Robotic Buildings: a study on a robotic building which is able to consciously change its form and adapt to occupants, needs and environmental conditions.

7 Conclusion

The chapter outlined how the fusion of Microsystems technology and robotic technology with our daily environment and thus services tasks has advanced over the last decades. Today not only researchers are interested in this technology fusion but also companies from various fields increasingly become interested in developing such applications for the growing care and home care market. With two major research projects aiming at customizable and by robot technology supported personal health environments the authors are currently pioneering a new application area for advanced technologies. Buildings are characterized by a long life cycle. This fact is not just economically and ecologically significant, but also relevant for the quality of life of its occupants. In order to generate added value of future real estate, a forward looking design is required so as to ensure numerous high performing living environments. Similar as the increasing share of electronics in cars we will experience more ICT, microelectronics, and microelectronic or mechatronic systems for future life adaptable architecture. Future buildings will provide more services. Specialists like Bill Gates predict that ICT based services will enhance our daily life and increase its market share as the personal computer did in the 1990ies. The success of future real estate will depend on the blending of passive architectural with active microsystem technological functionalities. Based on the authors activities the Technical University of Munich (TUM) established the new master of science course in Advanced Construction and Building Technology (ACBT, 2011), starting with the winter term 2011/12. The Master Course will be hosting international students and professionals from various disciplines, such as architecture, civil engineering, mechanical engineering, electrical engineering, computer science, economics, medicine, and others. The topics of this course aim at expanding the professional core competence in construction while responding to changing technological, social and ecological circumstances:

- New technologies, processes and strategies for designing and producing of buildings
- Integration of intelligent systems in daily life and environments
- Life cycle management, value engineering and design, innovation

The philosophy of the Master Course is characterized by its interdisciplinarity between disciplines as such as computer science, mechanical-, electrical engineering, economics, medical technologies, sociology, civil engineering and architecture etc. The existing and conventional knowledge and experience is being enhanced by redesigning or reengineering construction processes using/embedding automation and robotic technologies.

8 Online Resources

The online version of the chapter will be available on iConcept Press Website.

Appendix

Appendix should be put at the end of the chapter before Reference. You do not need to include any number before Appendix.

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