Compacted and Industrially Customizable Ambient Intelligent Service Units: Typology, Examples and Performance

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Abstract— **With fast proceeding demographic change, lack of qualified nursing staff and costs explosion concerning our health and welfare systems, new methods have to be developed to support elderly people in their home environment with ambient integrated and intelligent assistance/service technologies. Service units and related typologies presented in this paper are adding new layers of functionalities to conventional home care environments. To simplify implementation, service units shift the complexity arising with more and more complex high-tech buildings to a compact entity/unit which could be industrially prefabricated/customized and equipped with various assistance technologies in a controlled factory environment. Moreover, service units can be installed within new or existing buildings rapidly and with minimized effort as an additional building sub-module.**

Keywords: Home Care, Service Units, Ambient Intelligence, Mass Customization

I. INTELLIGENT HOME SERVICE ENVIRONMENTS

On the one hand microprocessors, microelectromechanical systems (MEMS), cameras, sensors, actuators, robots and other smart devices are gradually permeating our built environment creating new layers of functionalities [1]. On the other hand, with fast proceeding demographic change, lack of qualified nursing staff and evolving costs explosion concerning our health and welfare systems, new methods have to be developed to support elderly people in their living environment at home [2] with new functionalities enabled by integrated, networked and intelligence supported assistance/ service technologies. Yet our built environment often is complicated to change or "upgrade" to an advanced ambient intelligent environment, use cases are complex, environmentally integrated technologies are hard to maintain and service, and finally customer integration and personalization are of extreme importance in ambient health environments. Further, it has to be discussed how complex micro-electromechanical and robotic systems can be deployed and integrated with the building in a calm and invisible manner.

A. Home Service Environments

The stay of elderly and needy people in their well known home environment is related to several difficulties as homes are in most cases inflexible and not equipped with appropriate assistance technologies [3] or sensor/actuator systems which allow for ambient intelligence [4] and improved quality of life. Especially when entering a later stage of life, changes in life-styles, requirements, habits and activities are most dramatically. Unexpected diseases and unforeseen courses of diseases occur and are related to a tendency towards multi-morbidity [5]. Regarding the organization of the domestic environment, this means that for meaningful and effective maintenance of functionality in many cases, a fundamental change of spatial configuration and interior design, a renewal of the basic technical equipment [6], or the additional introduction of new technologies, ambient intelligence and other assistance/service functions would play an important role. Yet, our built environment in most cases lacks open building systems [7] and easy changeable frameworks. In general "re-configurations" or "upgrades" are a complex, costly and time consuming enterprise, often forcing elderly people to accept severe limitations in quality of life or finally to move to a care facility [8].

B. Complexity of use cases

Especially concerning elderly people, "use cases" are in general a complex mixture of preferences and multiple geriatric requirements [9]. Support has to cover a multitude of quite different activities and disabilities: daily physical activity, mobility, hearing and seeing, cognitive abilities, emotional and psychological state, social interaction and emergency situations [10]. Consequently, this requires a complex set of methods, processes and technologies [11] of different professional areas. Some requirements can be met with highest efficiency by "architecture/design concepts", some by "sensor/actuator systems" and "ambient intelligence" and others by environmentally integrated "mechatronics", "geronto-technologies". Upcoming new service areas based on ubiquitous computing, continuous health monitoring, tele-consulting and tele-medicine moreover enhance and extend the potential of today's intelligent service environments [12][13]. As in most real-life service situations various and complex requirements have to be met at the same time to address a specific "use case" in a holistic way, the potentials of all of the mentioned professions have to be combined to an integrated approach for intelligent home-service environments.

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C. Ambient Integrated MEMS/Robotics

Creating an environment for elderly people needs to integrate different sensors and actors into many daily objects. Such objects, so-called netgets [14], comprise distributed, networked computing using their own integrated intelligence to calmly do support human tasks, as envisioned by Ubiquitous Computing. We find many sensors and actors in our Environment: the open/close sensor of the refrigerator, the PIR sensor on the automatic sliding door, or the temperature sensor of the building HVAC system etc. Adding communication between such dedicated sensors makes it possible to combine distributed knowledge, analyze data, and support people more efficiently during their tasks and life situations. Reducing the many different application areas and functionalities of ubiquitous computing devices to this very usage scenario, we encounter many sensors and actors along such a living unit:

- Motors and Mechatronic Subsystems
- Contact/Resistive Touch Sensors
- Lighting Devices
- Alarm/Emergency Services
- Movement/Activity Detection

In the special case of pervasive healthcare it is also common to use special (bio-medical) sensors. Common sensors in this application area are:

- Heart Rate Monitoring
- Air Quality Sensors
- Heat Sensors
- Glucometer
- Spirometer
- Skin Conductance
- Blood Pressure Sensors

As we combine these distributed sensors and actuators, we gain much more possibilities to help people during their daily routine and activities. With sub-systems, networks and performances becoming more complex and autonomous, the total system can be considered as a new type of distributed and Ambient Integrated Robotic (AIR) [15] system, also developing emergent behavior. Already in 1961 Engelberger wondered if relegating MEMS and robotic technologies to only industrial applications makes any sense: "The biggest market will be service robots" [16]. Today, robots and distributed robotic sub-systems actually start to permeate our every day surrounding home/town environment [17], enhancing it with a multitude of services and additional performances. At the same time, this permeation is likely to dramatically transform our perception of robotic systems, robot technology, robots' performance and the environment they are becoming merged with. Future robotic systems especially in the area of home care will be invisible and immobile systems, integrated and merged with furniture, appliances and building components.

D. Customization and Personalization

In terms of service environments, health care and individual assistance, the customization [18] and personalization [19] of treatments, processes and technologies to certain circumstances and/or use cases is of particular importance. This is an observable trend and directly affects course of disease and life-quality [20]. Given the multitude of possible use cases, diseases and treatment requirements, component systems that are based on modularity [21] and underlying platforms able to be customized to meet exactly the needs of a particular person are required to create efficient and acceptable intelligent home-care environments. Emerging forms of customer integration and customer co-creation [22], combined with innovative fabrication strategies and envisioned cognitive factories [23] can help to link needs and requirements directly and more or less in "real-time" to the delivered solutions/functionalities. A prerequisite for creating highly customized and personalized health and home care solutions is the consideration of system architectures, design variations and subsequent fabrication and service processes from the development stage.

II. Concept Derivation

The service unit concepts presented in this paper aims at the implementation of customized, performance added, reliable and affordable intelligent service environments through making use of the latest strategies in component system based building architecture/fabrication and customer integration strategies. The following section first gives an overview over Japanese frontier approaches and further develops a concept to solve the particular problem of servicing elderly people through intelligent, affordable and rapidly deployable high-quality ambient assistance environments in their own home.

A. Background

Japanese prefabrication companies as Toyota Home (Skeleton and Infill) and Sekisui Heim (Unit Method) have successfully transferred component systems and related production line strategies into housing industry. In factories steel frame units, serving as chassis, are customized to customer needs. Depending on size of the house 10 to 15 of those steel frame units are later assembled on site to build up a complete house (Fig. 1 and 2). About 80 to 85% of the construction and assembly work is done on the production line. Within the factory, the modules are already equipped with installations, technical subsystems, kitchen appliances and bath equipment. On the site, only simple joining and assembly work remains and the setup of the house is basically done within one day. Research has shown that this method of industrialized fabrication of buildings especially pays off the higher the degree of integration with high-tech subsystems of single units (especially bath or kitchen related units) or of a whole building is. Due to the high degree of controlled factory processes, the failure rate decreases meanwhile the building's quality and long term reliability is enhanced. This is of particular importance with the development towards buildings being more and more equipped with smart sub-systems, sensors and actuators. Toyota Home offers guarantees of up to 60 years including free maintenance of the building and its technical sub-systems – well knowing that it can rely on its products. Further, similar to car industry, gradually improving fabrication and organizational processes are used to lower the impact of more and more intelligent sub-systems being installed in buildings. Sub-systems as for example kitchen equipment, bath equipment, heating, ventilation and home automation systems are available from a multitude of n-Tier suppliers giving the customer the ability to customize the building to his preferences and needs.

Figure 1. Production line completion of fully equipped and functional "plug-and-play" Units, Sekisui Heim, Japan, Copyright T. Bock

Figure 2. Completed Units leaving the factory, Sekisui Heim, Japan

B. *Concept and Implementation*

In this paper an approach is presented which tries to transfer the basic idea of industrialized production methods to the area of Intelligent Environments. In Intelligent Environments, a multitude of embedded and distributed microcontroller systems, sensors and actuators are integrated – adding not only functionalities but also technology, making the building a more and more complex "product". Conventional on-site construction has particular disadvantages concerning the integration of highly complex sub-systems and components required in intelligent environments, as well as in ensuring their long-term quality/ maintenance. Moreover, buildings equipped just with a rather low degree of integrated microcontroller systems, as it can be offered already today, turn out to be costly and unaffordable enough. *Both quality/maintenance and cost aspects can be seen as major obstacles for implementing intelligent environments and their functionalities now and in the future in a greater scale for the support of home care issues*. The service unit concept takes up the advantages of highly industrialized, modular and customizable building products meanwhile eliminating some of the disadvantages of the method outlined in the former section. In contrast to the unit-method applied by Sekisui and Toyota, the presented service unit concept does not require a whole building being built from scratch. The service unit presented in this paper itself works as compact sub-system of the building and could be installed within both new *and* existing buildings. It directly connects to building´s supply infrastructures, takes up basic functions, as bath or kitchen, and concentrates home automation and sub-systems required for ambient intelligent environments and health supporting functionalities. Service units shift the complexity arising with more and more complex high-tech buildings to an compact entity which could be industrially prefabricated in a controlled factory environment and moreover installed within new or existing buildings rapidly. To meet different installation conditions, service units can be delivered to the site as modular kit or as pre-installed fully completed high-tech unit. Moreover, service units are designed to be installed as fully functioning units within less than 1-2 days thus minimizing the interruption of daily activities and care processes.

C. *Integration of ambient entilligence through compacted service units*

The service unit as a system in total including a common technological platform and compatible service functions has been designed as an invisible and immobile robotic system. The use case specific subsystems works seamlessly and to a high degree autonomously in the environment's and especially the service unit's background. The service unit concept thus make use of the strategy of embedding microelectro-mechanical systems (MEMS), cameras, sensors, actuators, robots and other smart devices into environments seamlessly and calm through the insertion of compacted service entities into new or existing homes. Compacted service units can be placed at strategically important locations helping to abate physical and cognitive disabilities to an acceptable ratio thus allowing for continuing daily activity and assisted care process at home. Although they do not supplement fully networked homes, which certainly would allow for much more functionality, compacted service units provide an affordable alternative able to be deployed easily and containing basic and "mission critical" functionalities needed for home care. Intelligent devices distributed over the living environment which are not an integral part of the service unit can be networked with the service unit wirelessly connecting them to central ambient intelligent control logic. Moreover, Service Units are scalable systems which can be deployed in parallel to existing functionality (e.g. bath, kitchen) and which also can be used to substitute existing functionality. When needed they can be integrated into the home service network and connected to water, sewage, lighting, ventilation heating and communication infrastructure. Configuration, operational setup and help, maintenance and re-configuration of the service unit will be performed by a care service provider which is leasing units and the various exchangeable and individually chosen subsystems to care receivers.

III. TYPOLOGY AND EXAMPLES

As use cases and requirements are usually huge in variety [10], basic typologies for smart service units have been identified in a first step of an R&D project. A simple Service Core (Typology A) unit with retractable and mechatronic assisted units states the "light" version; it appears as a fancy artifact which concentrates smart technologies to support life-quality, communication and light motor disabilities. The Service Wall (Typology B) goes one step further and supports also sever somatic, motor and cognitive disabilities. The Service Core (Typology C) finally is a designed as a "hospital at home", serving people which otherwise would rely on stationary care in a care facility. All typologies share a common technological platform which integrates sensors, actuators, appliances and assistance technologies in a compact unit to enable digital environments and ambient intelligence for home care scenarios. Moreover, all typologies follow the strategy of making sensors/actuators, appliances and assistance technologies "calm" [24] and invisible in order to achieve natural and acceptable environments.

A. Typology A: Service Core

The prefabricated *Service Core* is a typology that could be used to break up conventional room partitions and to create floating rooms around it (Figure 3.). It is placed in the middle of a room, house or flat and organizes customized functions as kitchen, bath and/or sleeping circularly.

Figure 3. Servic Core unit placed in an appartment to organize functionalities (Picture: V. Geywitz)

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 this 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. When the user wants to cook or use some kitchen appliances, those functionalities are pushed out form the core on demand or proactively building up the kitchen space immediately and temporarily. After that – based on user demand and/or on user behavior – the kitchen functions can be retracted into the core making the core appearing as a wall or a fancy piece of furniture. With retraction the modules are automatically cleaned and sanitized if necessary. Similarly, other functions as sleeping area or bath functions can be activated and deactivated by the user on demand or triggered by the user's behavior patterns. In contrast to service units typologies B and C presented later, the service core is designed as a system for supporting rather moderate disabilities. As all modules and integrated appliances are equipped with motors, especially moderate motor disabilities of the user could be assisted and counterbalanced by the service core to a certain degree. The modules can adjust to the user's needs and ergonomics through their state of retraction and their ability to adjust in height to a certain degree. Further, the service core is equipped with basic functions for light and sound control, video telephony and health monitoring. Health monitoring could be supported by various optional devices as Glucometer, weight measuring system, activity detection and a system for blood pressure measuring. Moreover, the core's system platform can connect to e-watches and/or a multitude of other wearable sensors. The activation of functions of the core by the user over a day or a certain time period is effectively used to generate precise activity and personalized health patterns.

B. Typology B: Service Wall

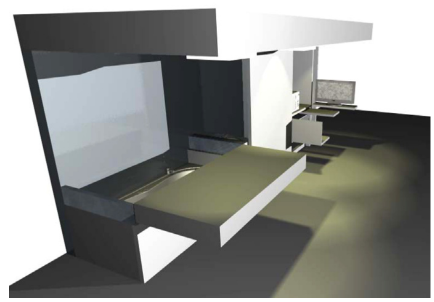

Figure 4. Service Wall with mechatronic supported functioalities and intelligent aplplications melting furniture, wall and asistive high tech functions into one high-performance system (Picture: P. Graab)

The prefabricated *Service Wall* melts usually separated systems as "wall" and "assistive furniture" into one system combining them with mechatronic sub-systems [25], sensors, actuators and ambient intelligence. The system (Figure 4.) could be erected besides 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. It 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. An installation back wall unit takes up technical installations, cables, microelectronic components and aeration. A suspended ceiling is also part of the system integrating controllable/self-controlled ventilation and lightning systems. To the suspended ceiling, moreover, an in-house overhead lift system is attached over the service wall's full length (Figure 5.). The overhead lift system could be customized by its individual straps and slings to specific use cases and physical conditions. The individual straps and slings are attached to a standard bracket and are fastened there with a simple click. With a remote control needy people can control the movement of the overhead lift to any location within the constraints of the service wall. All motions are tracked by the system continuously, in order to detect emergencies as early as possible.

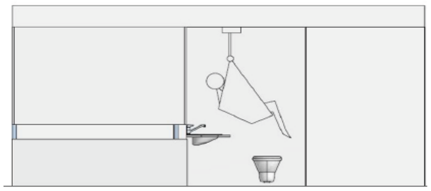

Figure 5. Overhead lift attached to a suspended ceiling beiing part of the Service Wall concept

Subsystems and appliances integrated in the service wall are connected to a generic platform providing control via ambient intelligence and/or various interface systems that could be chosen individually. Similar to typology A, the platform of the service wall allows for health monitoring through various sensors distributed in wall or ceiling and for the communication with service centers, emergency systems or telemedicine services. All in all, the service wall allows people with strongly restricted mobility to avoid a long-term stationary stay in a hospital or care facility. Through the Service wall the user receives all necessary assistive, geriatric and medical functions at home. As all appliances including toilet, washing basin and oven are smart appliances connected to the platform and an appliance manager, an enhanced security and safety concerning usage failures, overheating and water leaks could be guaranteed to care receivers, care helpers and relatives.

C. *Typology C: Service Room, a hospital at home*

The prefabricated *Service Room* is a unit which could be integrated into flats as a "room in room" system (Figure 6.). 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, 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. Bath appliances, kitchen appliances and resting place are distributed within a compact space thus reducing physical and cognitive stress for patients with highly constraint activity. Moreover, the bed is able to transform into a movable seat from which both bath appliances and kitchen functions could be used easily. Within the service unit, the health condition of the handicapped person is continuously measured and cameras allow relatives, doctors or service personnel to observe the patient and check his condition immediately in case of potential emergency. For personal health monitoring various sensor packages are available. Relatives or doctors can communicate with the needy person via a communication screen integrated in the back wall of the room unit.

Figure 6. Service Room placed as room-in-room entity within the appartment of an existing/old building (Picture: F. Roedel)

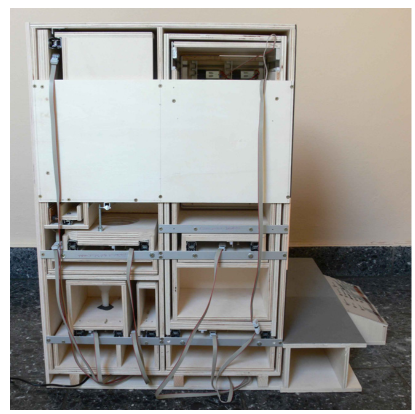

Figure 7. Fully functional experimental scale model of a exemplary service unit element

Although the service room provides a highly controlled medical in-house environment, the handicapped person is enabled to stay in its well known home environment. With the help of relatives and/or service personal the handicapped person might also be able to leave the service room for activities in other areas/rooms of the flat temporarily. All in all the service room has the function of a very compact hospital or care facility deployed at home. Its intention is to provide severely handicapped persons the possibility to stay at home as long as possible through the interplay of functional architecture, embedded microcontrollers and ambient intelligence within a performance added and compact modular service unit.

IV. Actual Stage of the Research

In a laboratory test bed fully functional scale models of the discussed typologies are equipped with sensors, actuators and pervasive computing middleware. The hardware platform used is the Arduino platform, a recent prototyping platform and toolkit. This platform makes it possible to control both analog and digital inputs and outputs. By connecting an extension board (a so called "shield") we gained additional functionality such as more space for complex circuits or wireless communication between different sensors/sensor networks. Moreover, the scale models are used to verify the outlined modular kit concept and to gradually implement ambient intelligence. Further, as the service units itself are conceived as an ambient integrated and distributed type of robot, the scale models will be used to verify this idea. In a next step, one of the typologies will be implemented as 1:1 prototype in a test bed at the university.

V. CONCLUSION

Both the factory production of Sekisui Heim and Toyota Home are based on assembly line production: moving steel frame units are customized due to floor plans, functionalities, technical infill and finishes demanded by an individual customer. Sub-components are fabricated in parallelized processes on various floors. A production line based fabrication could be applied as the buildings are broken down into 3-dimensional units of controllable size which could be sent as chassis through the factory for subsequent completion. The service unit concept takes this approach even one step further by reducing the size of the units and by making them more compact through the integration of as many assistive and intelligent high-tech subsystems, sensors and actuators as possible on less space. Similar to automotive industry service units are kits which concentrate complexity on a compact unit or wall thus allowing for industrialized high quality and low-cost manufacturing in a highly-controlled factory environment. Moreover, the service unit approach tries to simplify the integration of advanced assistance technologies into existing homes and allows for equipping the home with complex medical sensors, monitoring equipment assistive appliances and embedded service robotics. The service unit is a compact, modular and customizable service entity, equipped with technology packages, bound together for supporting certain disabilities or sets of disabilities. The service unit contains all needed functions and assistance technologies which thus do not have to be distributed over the whole flat. The service unit is also considered as a new type of Ambient Integrated Robot as it makes use of the concept environmentally embedding complex and networked MEMS into environments. As only the service unit has to be installed in the home as a compact prefabricated and pre-configured module to deploy an advanced assistive environment, system cost and complexity of the rearrangement/renovation are minimized. Medical issues and the technical integration of "plug and play" pervasive and assistive health technologies into service units are discussed in detail in [13].

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