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HOME “SMARTNESS” - HELPING PEOPLE WITH SPECIAL NEEDS LIVE INDEPENDENTLY

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Abstract:
An inclusive and sustainable society has to use its resources in an efficient manner to support people with special needs (elders / people with disabilities). New, intelligent technologies could help the minimization of expenditures for assisting people with physical and cognitive limitations to live independently. The paper analyses the impact of conferring smartness to different functions and sub-functions of home equipment to increase the capacity for an independent living for such situations. This capacity is assessed with the indicators of the (UK FIM+FAM) scale and their correlations with the smartness of home equipment functions are analysed with tools and techniques of competitive development and value engineering. The analysis leads to a set of functions / sub-functions of lighting, heating, security, media, furniture, etc. that, if receiving smart abilities, could have a critical contribution to the independent living capacity of people with special needs. In this context, for these functions, the investment in developments and innovations that increase their degree of smartness is justified.

Keywords: ambient intelligence, ambient assisted living, people with special needs, independent living, decision support systems

1. INTRODUCTION

A study on aging prepared by the European Commission, predicts "dramatic changes" in the age structure across the European Union over the next 50 years. It is projected that by 2060 those aged 65 and over will occupy 28% of the population (rising from 18% today) and those aged 80 and over will represent 12% of the population (increasing from 5% today). The shift is so considerable that “the EU would move from having about 4 working age people for every person aged over 65 years to two working age people for the same person” (European Commission 2014). Enabling the increasing elderly population to live fulfilled and independent lives while at the same time optimizing the increased public expenditures on long term care caused by the changes in demographic structure should thus become a priority over the following years.

Aging in place (the ability to live in one’s home as opposed to a healthcare facility such as a nursing home) offers several advantages over long term institutional care. From a personal point of view aging at home increases elderly peoples’ quality of life by increasing social participation, personal security, limiting the negative effects of relocation such as confusion, alienation and speeding up mental and physical decline. Also aging in place can contribute to preservation of cognition, decrease in depression and prevention of incontinence (Henkemans, et al. 2010). From a public point of view helping seniors age in place has the potential to significantly reduce public spending on long term care by up to five times (Rousseau, Firth and Jankiewicz 2013).

Natural aging is associated with certain physical and cognitive impairments such as sensing, information processing capability, speed, timing and precision of movement etc. (Blasco, et al. 2014). Adding to these is the increasing risk of chronic diseases and the varying inherent disabilities affecting cognition, motor function, sight, hearing etc. All these impairments represent threats to the elderly person’s ability to age in place independently. One possible solution for overcoming these impairments is embedding Ambient Intelligence (AmI) into living environments, also called Ambient Assisted Living (AAL). Smart technologies and concepts such as AmI and AAL are still an emerging field yet their salience is proven by the wealth of academic literature which associate the term “smart” with all scales of human living environments, from “smart earth” (Li, et al. 2014) and “smart cities” (Chourabi, et al. 2012), down to “smart homes” (Ghaffarian Hoseini, et al. 2013) and “smart furniture” (Amutha, Sethukkarasi and Pitchiah 2012).

Several papers (Henkemans, et al. 2010) (Queiros, et al. 2013) identify a general focus on integrating specific technologies into an AAL context instead of identifying the users’ needs and finding ways to satisfy them. This tendency, combined with an industry dominated by suppliers lead to an approach that is “technology-push, rather than demand-pull”, lacking in user centric design and user friendly applications (Henkemans, et al. 2010). Thus, the question we pose and wish to answer is how can an AAL environment be optimally tailored to the specific needs and defining disabilities of a given subject. To address this issue we propose an approach that evaluates these needs (in this case defined by the UK FIM+FAM independence evaluation scale) within a QFD correlation matrix against functions of an AAL system and identifies those solutions which are critical to independence for that particular user.

2. THEORETICAL FRAMEWORK

The method we propose operates at the convergence of two distinct fields. On the one hand we have the Ambient Intelligence paradigm and on the other, the care and independence of people with special needs, be these caused by old age or by chronic condition.

2.1. Ambient intelligence

On a conceptual level Ambient Intelligence (AmI) can be defined as an environment infused with “pervasive and unobtrusive intelligence that is able to proactively support people in their daily lives” (Queiros, et al. 2013). AmI eliminates traditional input and output media such as mouse, keyboard and screen and replaces it with direct interaction with the environment. (Sadri 2011) The AmI environment becomes a system that can sense its surroundings, process the information, react to the stimuli it gathers and automatically adapt to changing situations.

On a technological level AmI refers to the integration of ICT (Information and Communication Technologies) into the various systems of the environment. (furniture, appliances, building infrastructure etc.) All of these technologies have the ability to communicate with each other and the outside environment and, with the help of sensors and actuators, they can "adapt the environment to the users' needs in a transparent and anticipatory manner" (Acampora, et al. 2013) Directly related to the Ubiquitous Computing, AmI inherits the high degree of technological integration into the environment yet it shifts the focus from specific technical implementation to people and their needs (Bick and Kummer 2010). Following a survey into Ambient Intelligence in Healthcare (Acampora, et al. 2013) the authors have identified a series of characteristics which are common to AmI systems:

- Context aware: it exploits the contextual and situational information;
- Personalized: it is personalized and tailored to the needs of each individual;
- Anticipatory: it can anticipate the needs of an individual without the conscious mediation of the individual;
- Adaptive: it adapts to the changing needs of individuals;
- Ubiquitous: it is embedded and is integrated into our everyday environments;
- Transparent: it recedes into the background of our daily life in an unobtrusive way.

2.2. Ambient assisted living

Ambient Assisted Living (AAL) is a direct application of AmI. It integrates ICT technologies into the living environment of a person with special needs to improve their independence and enable aging in place. AAL are a sum of "technological solutions that will enable the elderly population to maintain their independence for a longer time than would otherwise be the case" (O'Grady, et al. 2010).

These technologies' purpose is two-fold. On the one hand they monitor and log every aspect of the person living in the environment. This helps health care professionals to track, diagnose and treat their patient without the need for them to be interned in a health-care facility, and it also detects crisis situations such as seizures or falls and automatically contacts emergency services and the family of the person. On the other hand these technologies assist the inhabitant directly by compensating for failing abilities or senses of the person by either replacing them directly (replacing the ability to walk with a wheelchair) or by shifting them to a sense or ability that has not been compromised (visual aids for a person whose hearing is compromised, or speech recognition for persons with poor visual letter recognition (Lopresti, Mihailidis and Kirsch 2004).

Several challenges to the wide-spread adaptation of the AAL have been identified by authors (Lê, Nguyen and Barnett 2012). These usually fall into one of three categories:

- Financial accessibility – the advanced technologies used in AAL homes are still mostly expensive to acquire, install and maintain. "It is important therefore that governments and stakeholders at various levels collaborate in planning and implementing smart homes for older people" (Lê, Nguyen and Barnett 2012)

- Technical accessibility – Older people can be less comfortable with the high degree of technological integration required by an AAL home. Operation of such a home can be difficult and unwieldy and special care must be given to user friendly design and gradual introduction into the environment.

- Psychological accessibility – Older generations tend to be less tolerant to excessive technology use, and react with a combination of "mistrust and uncertainty, anxiety of being controlled, and fear related to the loss of privacy" (Lê, Nguyen and Barnett 2012). These fears must be addressed and trust must be cultivated if acceptance of the environment is to be raised. Also a stigma associated with AAL homes has been addressed by implementing a "mainstreaming approach" which involved making the technology available to all members of a community, "the rational being that if everyone had the technology then technology would not be an indicator of decline in function" (Reeder, et al. 2013)

2.3. Measuring independence – the UK FIM+FAM scale

The Functional Independence Measure and the Functional Assessment Measure (UK FIM+FAM) scale is a widely used measurement system for the outcome of patient rehabilitation programmes. It assesses a person's independence by evaluating requirements for assistance with essential tasks of daily living (Turner-Stokes and Siegert 2013). The system is based on FIM+FAM, a scale developed in the US in the 1980s, used for evaluating outcomes after traumatic brain injuries (Turner-Stokes and Siegert 2013) This was developed further by a group in the UK (The UK FIM + FAM Users Group) reaching its final structure in 1999 after increasing scoring consistency and expanding its scope to include several Communication, Psychosocial and Cognition traits (Gupta 2008). The scale was expanded further with a module evaluating Extended Activities of Daily Living proven to be a reliable addition.

The final structure of the scale assesses 35 items divided in 2 or 4 categories (Turner-Stokes and Siegert 2013) and assigns scores from 1 to 7 based on the degree to which the patient needs assistance in regards to that item, where 1 represents total dependence or inability to perform that activity, and 7 represents total independence. Of particular interest in an AAL context is the grade 6 which refers to “modified independence”, that is the ability to perform the activity assisted by devices but without physical help. Basic training for evaluation lasts upwards of 1 hour and the evaluation itself lasts 30 minutes and can be administered by a physician, nurse, therapist or even a layperson (Gupta 2008).

The UK FIM+FAM is thus a mature, well established system which is comprehensive, easy to implement and has proven to be relevant in long term care evaluation, making it well suited for using it to determine the needs of a inhabitant pertaining to AAL.

2.4. Competitive development and its instruments

Quality Function Deployment (QFD) – QFD is an integrated decisional method used for identifying the client’s needs from the beginning of the product development phase and to convey those throughout the design and production phases up until the final product. The method relies on a set of planning and communication routines which coordinate the different departments involved in product development (design, production, marketing etc.) so that the final product will be appealing to the consumer. The foundation of the method lies in the belief that a product must be developed starting from the consumers’ needs and tastes, therefore an interdisciplinary collaboration of all departments involved is necessary from the very beginning of the development phase (Clausing and Hauser 1988).

(Franceschini 2002) identifies several objectives of QFD:

- Defines the product features which satisfy the client’s needs
- Structures all the information relevant to developing a new product or service
- Defines the product as a relation of needs and features and compares this definition to the competition’s
- Reduces the risk of costly corrections in the advanced stages of product development since it takes into consideration all defining factors from the first stages
- Guarantees coherence between product and process planning

Due to its wide spread use, ability to translate customer needs into solution features, and accuracy in analysis of correlations between needs and features, we have found QFD to be an appropriate method in our approach.

Analytic hierarchy process (AHP) – is a method aiding in multi-criterial decisions. Its analytic component deconstructs the problem into its constitutive elements, which are then hierarchically arranged to reach a final judgement of comparative value (Bertolini, Braglia and Carmignani 2006).

Researchers (Forman and Gass 2001) have broken down the AHP method into 3 basic functions:

- Structuring complexity
- Measuring on a ratio scale
- Synthesising – considered equally important to the analysis facilitating hierarchical structure of AHP, is the AHP’s ability to measure and synthesize the multitude of factors in a hierarchy (Forman and Gass 2001)

From a methodological point of view, AHP is composed of three phases. Firstly the problem is broken down into constituent parts and these are arranged in a hierarchy tree made up of multiple levels. Secondly the tree is evaluated by pairwise comparison of each cluster on the same level. Seeing as the values assigned are based on subjective judgements there is a risk of inconsistency. To counter this fact a final operation is performed which verifies consistency across all comparisons. “If the consistency ratio exceeds the limit, the decision makers should review and revise the pairwise comparisons" (Ho 2008) (Bertolini, Braglia and Carmignani 2006).

Due to its great simplicity and flexibility AHP has been routinely integrated into other techniques and methods such as QFD, meta-heuristics, SWOT and DEA. For the purpose of our study we were especially interested in the integration of AHP in QFD. The importance ratings of customers' requirements needed in a QFD analysis are usually determined arbitrarily by the decision makers. Integration of AHP reduces the inconsistency caused by arbitrary value judgement.

3. METHODOLOGY/RESEARCH

3.1. Identification of subject needs

As previously stated our approach aims to shift the focus from the general "technology-push" tendency to a user centric approach in configuring a customized AAL environment. To achieve this we will consider developing a new AAL environment as any other new product with the elderly or disabled person as our customer. If our aim is to enable them to age in place independently it is reasonable to equate their needs to the 35 items of the UK FIM+FAM scale with the added module for EADL (Extended Activities of Daily Living). These have been proven to accurately assess aspects of a person's independence and therefore can be used to identify those aspects where the environment could compensate for failing functions. For a comprehensive analysis all 35 items can be input into the analysis, yet this being an approach tailored to the individual, it is possible to divide the items in two or four sub-dimensions as proposed by (Turner-Stokes and Siegert 2013) and only analyse those sub-dimensions that pertain to the person's defining disabilities. For example one could only consider those items that refer to motor disabilities if the person who is to live in the environment shows no cognitive disabilities.

For the purpose of the analysis the actual scores the person has attained on the UK FIM+FAM evaluation is not directly used, but it is taken into consideration in evaluating the degree of importance of each of the items. Following the evaluation and an interview with the subject, operating in a small working group (which should contain a medical specialist) and using the AHP method we determine a relative importance of the items chosen to be included.

Table 1: UK FIM + FAM + EADL module – The work group can choose to include all of the items, one of the two sub-groups illustrated here, or one of the four further subdivisions (Physical, Psycho-social, Communication, and EADL)

Motor			Cognitive	
Eating Swallowing Grooming Bathing Dressing – upper Dressing – lower Toileting	Bladder management Bowel management Transfers – bed/chair Transfers – toilet Transfers – tub/shower Car transfer Locomotion	Stairs Community mobility Meals Laundry Housework Shopping	Comprehension Expression Reading Writing Speech intelligibility Social interaction Emotional status	Adjustment Use of leisure time Problem solving Memory Orientation Concentration Safety awareness Financial management

3.2. Functional analysis

In the next phase we perform a study of scientific literature (Hamernik, Tanuska and Mudroncik 2012) (Demiris and Hensel 2008) (Bregman and Korman 2009) (Manning and Kun 2009) (Lopresti, Mihailidis and Kirsch 2004) (Lê, Nguyen and Barnett 2012) (Chan, Esteve, et al. 2008) (Chan, Campo, et al. 2009) (Alam, Reaz and Ali 2012) to identify a list of primary and secondary functions of smart homes in general and health oriented smart homes especially. These have been divided into 6 functional groups:

1. *Lighting and shading*
2. *HVAC*
3. *Safety and security system*
4. *Multimedia and communication*
5. *Health*

6. Home maintenance

The work group decides which of these functional groups is relevant to satisfying the needs selected and identified in the first phase. These primary functions are then inserted alongside the UK FIM+FAM items in a QFD correlation matrix.

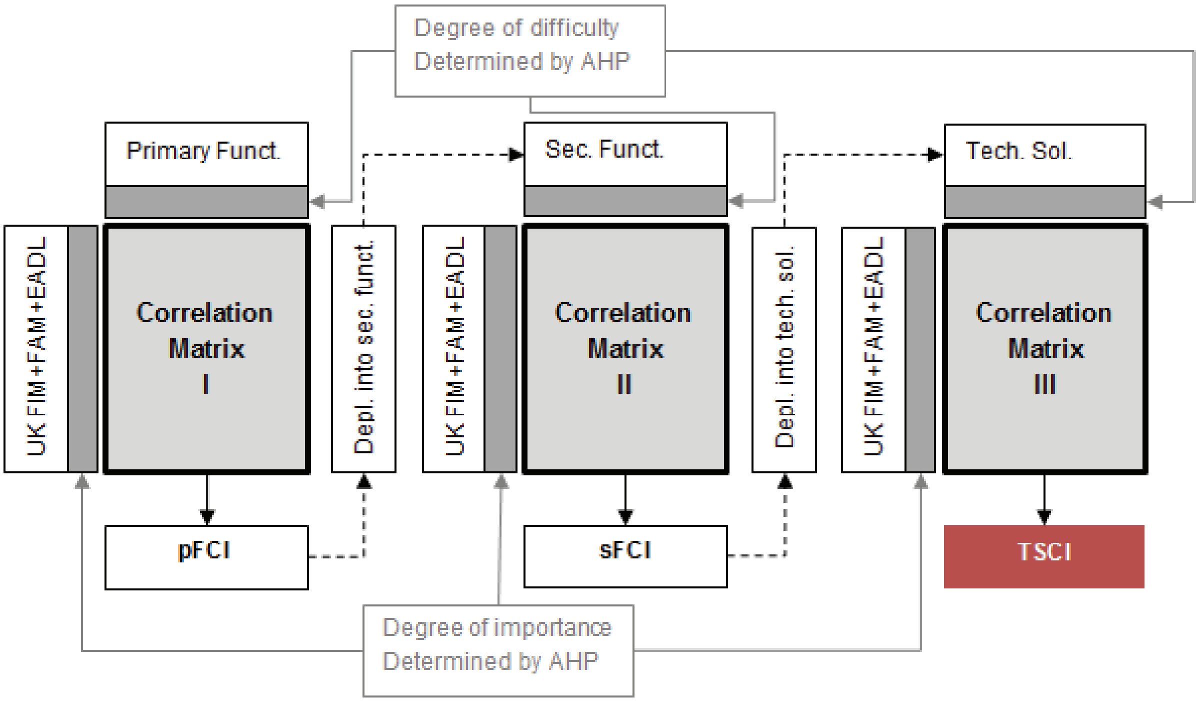
Table 2: Functional analysis of smart homes

Groups	Primary functions	Secondary functions	
Lighting and shading	-Local lighting -Navigation lighting -Emergency lighting	-Switching -Dimming -Motion detection -Lighting scenes -Reserve power source -Orientation control	-Lighting color -Local control -Central control -Remote control -Automatic control
	-Shading	-Local control -Central control	-Automatic regulation -Remote regulation
HVAC	-Provides heat -Provides cool air -Provides hot water -Provides fresh air	-Local control -Automatic control -Central control -Thermal energy recuperation -Optimization of resource consumption	-Individual temperature control for each room -Air moisture control -Communic. with weather forecasting
Safety and security system	-Monitors home for unauthorized access	-Video surveillance -Motion detection -Glass break detection -Identification of authorized and unauthorized persons	-Notification of authorities and family -Locking and unlocking of doors, gates and windows
	-Monitors home for hazardous situations	-Alarm system -Fire, smoke and gas leak detection -Flood detection -Remote access	-Smart sound monitoring system -Fall detection
Multimedia / communic.	-Media generation -Media consumption -Communic. with others -Telemedicine systems	-Video calls and conferencing -Phone calls -Access to the Internet -Synthetic voice generation	-Local control -Remote control -Central control
Health	-Collects data pertaining to physiological measurements	-Monitor pulse, respiration, temperature, blood pressure, blood sugar level, bladder and bowel output, weight etc. -Sleep monitoring	
	-Functional measurements and assistance	-monitoring of general activity level, motion, gait -Identification of consumed food and diet management -monitoring and identification of ADL (Activities of Daily Living) -mobility assistance (wheelchairs, lifts, platforms etc.) -rehabilitation and support robotics (exercise program) -personal hygiene assistance (smart toilet)	
	-compensate for sensory deficits and aids cognitive functions	-automated or self-initiated reminders -medication reminder and management -task instruction technologies	
Home maintenance	-automates activities related to the kitchen	-checking and replenishing stocks -water filtration system management -pre-treatment of selected food -self-adjusting furniture	
	-aids in cleaning and home maintenance	-automated cleaning robotics -self-cleaning systems -automated cleaning of sidewalks, gutters -automated clearing of snow from roof (thermo cables) -automated irrigation	
	-manages home appliances	-local monitoring and control -central monitoring and control -scenario programming and management	-automatic control -remote monitoring and control

3.3 Correlation analysis

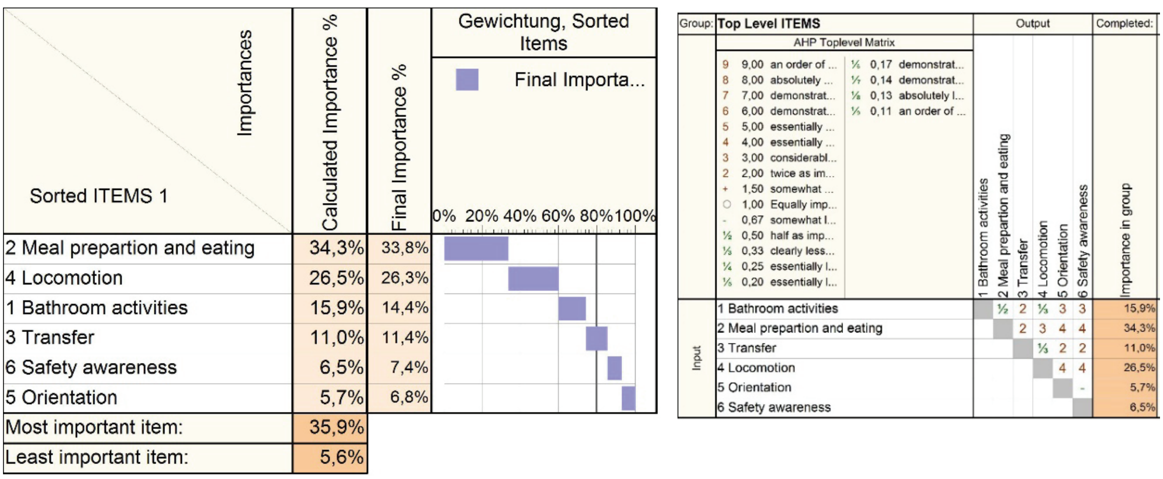
What follows is a cascading QFD analysis. The first one correlates the UK FIM+FAM items with the primary functions of the AAL environments and outputs a set of Primary Functions Critical to Independence (pFCI). These are deployed into secondary functions and correlated again with the UK FIM+FAM Items to output Secondary Functions Critical to Independence (sFCI). The third and final phase deploys the secondary functions into technical solutions into the third matrix to output Technical Solutions Critical to Independence (TSCI). This output represents the optimal configuration of technical solutions which can, with minimal costs, satisfy the needs of the subject.

Figure 1: Illustration of the cascading QFD analysis



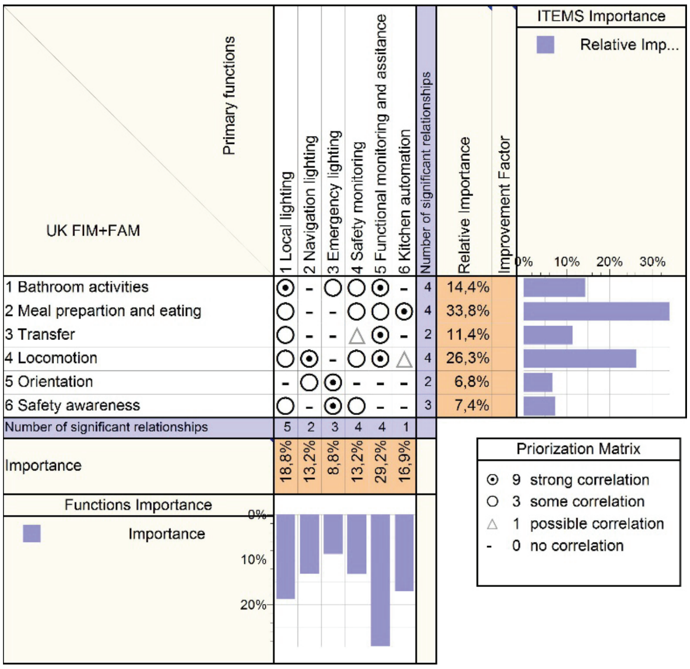
To illustrate the method we chose a limited number of FIM+FAM items and grouped them as input into the analysis. Grooming, bathing and toileting have been grouped into bathroom activities and all transfers have been grouped together. These have been analysed with the AHP method to determine their relative importance. The AHP analysis yielded a consistency index of 9%.

Figure 1: Example AHP analysis



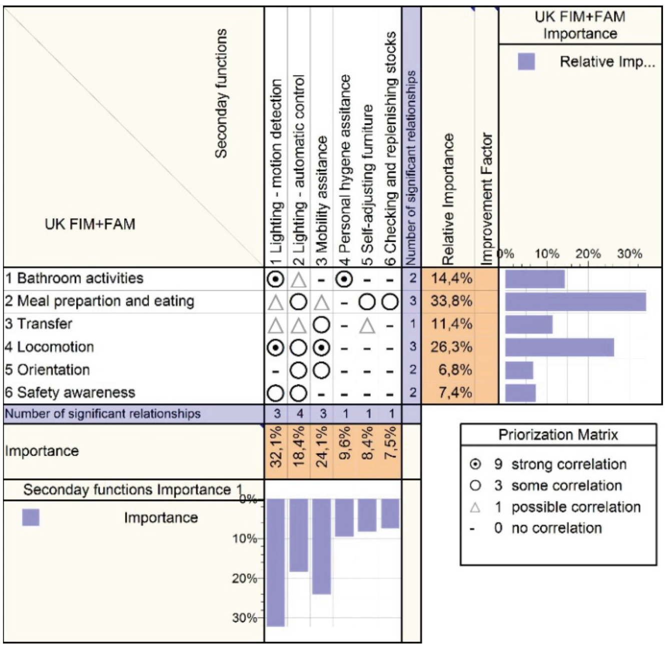
The FIM+FAM items chosen are inserted into a correlation matrix alongside a limited set of primary functions. The result indicates that of the functions chosen the most important ones are, in order, functional monitoring and assistance, local lighting and kitchen automation. These are then deployed into several secondary functions which are inserted into a second correlation matrix.

Figure 2: Primary function correlation matrix



The second correlation matrix indicates that the most important secondary functions, of the ones analysed, are, in order of importance, lighting – motion detection and mobility assistance. These can be further deployed into multiple technological solutions such as various types of sensors for motion detection, and various types of wheelchairs and/or mobile platforms for mobility assistance. Due to spatial restraints imposed on the paper we will not illustrate the last correlation matrix as we consider it to be similar in form to the ones already presented.

Figure 3: Secondary function correlation matrix



4. CONCLUSIONS

One of the main challenges faced by the AAL paradigm, as identified by (Lê, Nguyen and Barnett 2012), is financial accessibility. Designing, installing and maintaining smart home systems is a laborious undertaking which incurs high costs. If these technologies are to be implemented on a large scale, financial efficiency is of the utmost importance.

We believe this approach provides the decisional support necessary to arrive at a configuration of technologies which offers the greatest impact on the independence of the subject as opposed to a “one size fits all” type solution which would lead to increased and unjustified expenses. Our approach uses as input established measures for independence (UK FIM+FAM) and functions of a smart living environment and outputs those technical solutions which together form an AAL environment tailored to the individual.

One of the limitations of our approach is that it does not take into account the interactions and conflicts between the various functions and technical solutions used. Therefore future research will seek to replace the correlation matrix with a more mature House of Quality method which would identify where investment in innovative solutions is warranted. Also the introduction of a cost benefit analysis of the TSCI identified into the workflow would further increase the financial efficiency of the final output.

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