Co-creation of Smart Technology with (and for) People with Special Needs

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ABSTRACT
We report on the lessons learnt during the application of a methodology to develop Intelligent Environments. This methodology was applied to a project which aimed at helping people with Down's Syndrome and those with similar conditions and needs, to be more included in society. The project is developed by a consortium of commercial, academic, and end-user supporting organizations. One important feature of the methodology is that of being strongly user-centred and we report on how that interaction with users took place and how it continuously shaped the project.

Categories and Subject Descriptors
Ubiquitous and mobile computing, Human-centred computing, Software creation and management.

General Terms
Your general terms must be any of the following 16 designated terms: Design, Reliability, Experimentation, Human Factors, Measurement.

Keywords
Intelligent Environments, Human-centred Design, Software Development Process.

1. INTRODUCTION
Technology is finding its way through society and developed systems are increasingly intertwined with our daily lives. More recent systems are related to health, safety, socialisation, entertainment, information, and more. These systems are increasingly challenging to build, because in order to be useful wherever and whenever we may need their benefits, engineers need to rely on a mix of system components, which are complex on their own and even more when combined. This is not entirely new in Computer Science and Information and Communication Technology fields, which have been developing systems of increasing complexity for decades. One benefit of this rich history is that engineers now have a body of experience, methods and tools to use when embarking in creative processes.

On another hand, these methods are not infallible as we all experience on a regular basis when technology let us down one way or another. To make matters worse, the new systems which have spawn from the Ubiquitous Computing (Weiser, 1999) movement two decades ago have a mix of components and expectations which are slightly different than those which led to the development of the methods and tools most widely used up to recently.

There are several areas related to Ubiquitous Computing like Pervasive Computing, Internet of Things, Smart Environments, Ambient Intelligence, which largely share the objectives and building blocks, and which we will, collectively, refer to as Intelligent Environments (Augusto et al., 2013). These areas have in common (with different emphasis in each of them) the use of sensing technology and innovative interaction devices interconnected with a network and supplemented with intelligent and context-aware software to create useful services for humans in whatever space and time they need support. One of the many important hurdles in the way of this new area is the lack of methodologies and tools to support developers connected to a strategy which guides them through the process in a way which increase their chances of success.

New system developing strategies have been proposed recently based on the experience of the last decade of building sensorised environments (Augusto, 2014). High-level strategies have been used for a long time in Computer Science and there are well-established options like "waterfall" inspired methods and "agile" inspired methods, which were created in the 80's and 90's. After much debate and criticisms from defenders of each approach, there is now recognition these methods are not always the best option and they shine at their best only when the project to be applied to has certain characteristics. UC- IEDP, the development method used and assessed we report about in this paper is flexible enough so that it can be used in ways which can resemble either the waterfall or agile approaches, although the emphasis is more as a user-centred iterative process.

In this paper, we report on the application of UC-IEDP to an EU funded project and the insights gained in the process. The project lasts for three years and has significant complexity from the number of teams taking part, the diversity of roles, the diversity of expected products, and also the specific requirements brought in by the intended primary beneficiaries.

We describe the method in the next section, then in section 3 we explain the project it was applied to and in sections 4 and 5 we focus on the co-creation/co-design activities and how they continuously shaped the services being developed. We finalise with a reflection on the lessons learnt by this exercise and what it means for the Software Engineering community facing the new challenges of creating Intelligent Environments.

2. U-C IEDP

It has been acknowledged by researchers in the field of Intelligent Environments that there is limited research regarding software development methodologies for building and deploying such sophisticated environments, see for example Alegre et al., (2016).

Consistent with this perceived lack of any agreed standard on the software development methodology for building and deploying Intelligent Environments, Augusto (2014) proposed the User-Centred Software Development Process (UC-SDP), which was grounded on the experience of a decade building systems based on sensors. That initial name of the methodology recognized that software was one of the main components in the development of sensor based systems like those developed in the areas of Ubiquitous and Pervasive computing, Ambient Intelligence, Internet of Things or Intelligent Environments. The name of the methodology evolved into User-Centred Intelligent Environments Development Process (UC-IEDP) to emphasise it is not only software we consider in building these systems but also Hardware, Networks, and Interfaces. We assume the physical space where the system is going to be deployed, for example, the smart home, office, or shopping centre, is already built. Our focus is not the technological aspect, we are less concerned with the creation of artefacts (e.g., specialised sensors); we largely assume the sensors and devices to be used are available in the market. Our focus is in how to put together technology and create the software which makes the infrastructure provide the required services.

The purpose of this model is to guide developers build IEs which meet customer expectations and which are technically robust and correct. Because the final aim of products in this area is to satisfy users' expectations, one important feature of this systems creation strategy is the cognisance paid to the importance of stakeholders involvement of the project, in what is usually called in creative industries as "co-creation". A number of studies have established users as being critical since they are at the heart of Intelligent Environments (De Russis, 2014). Pennings et al. (2010) reported that success of an Intelligent Environment is mainly determined by the extent to which it is adopted by users. Corno et al. (2015) carried out an extensive literature review on the involvement of users in the research, design, development and validation of intelligent environments over the last 15 years. They also emphasised that IEs should be built with the users in mind and made a strong case for user-appreciated systems.

The UC-IEDP model has three primary loops: Initial Scoping, Main Development and IE Installation. Solid arrows represent mandatory steps while dashed arrows represent optional steps. The model consists of a number of smaller loops which allow refinements of the system based on stakeholder feedback. This also gives the strategy flexibility in the sense that a project can spend more time (possibly through several iterations) in each of these loops (in a more 'waterfall' fashion), or instead try to complete the entire process quickly and iterate that several times to target specific features (in a more 'agile' fashion).

A high level architecture diagram of the process model is given in Figure 1. The bold arrow indicates the expected main starting point. Arrows with full lines indicate typical flow whilst dotted lines suggest optional, perhaps desirable, alternatives to increase stakeholders involvement.

During *initial scoping*, requirements for the IE to be conceptualised are initially gathered by interviewing the stakeholders. This useful information is then translated into services which the system must provide. Next, the technical team work on the hardware requirements as well as interfaces for building the IE. An initial prototype is thus built and given to the stakeholders who assess the system based on their expectations and provide vital feedback to the developers.

Upon customer approval, the team moves to the next loop, *main development*. To begin with, a thorough design is carried out and various design documents are produced at this stage. These serve as a blueprint for building, validating and verifying the IE. Stakeholders are kept in the loop at this stage as well and their input is particularly valuable to avoid any unpleasant surprises in the future. The next step in this loop is coding and testing of the IE using suitable tools. Testing should be carried out on hardware, software and human-computer interfaces. A rigorous approach such as model checking is recommended to check correctness of the systems. Moreover, verification and testing should desirably be performed in conjunction to make sure system is correctly built.

The third loop is *installation* of the IE. Initially, the infrastructure is setup by installing various hardware components such as sensors, actuators, network interfaces. Next, the software is installed on the infrastructure and various stakeholders carry out functional test, to ensure the compliance. Any suggestions, changes or modification is reported and reworked. During services validation, the stakeholders test the IE continuously over longer period of time.

The model is also guided by an ethical framework to protect users from informal and rushed system development (Jones et al., 2014). This ethical framework is represented in the lower part of the methodology diagram because it is supposed to be considered during the whole process, in a continuous way, it should influence the conception of the products, developers should check the desired ethical complying features are present in the creation and also manifest in the behaviour of the deployed system in the real physical world.

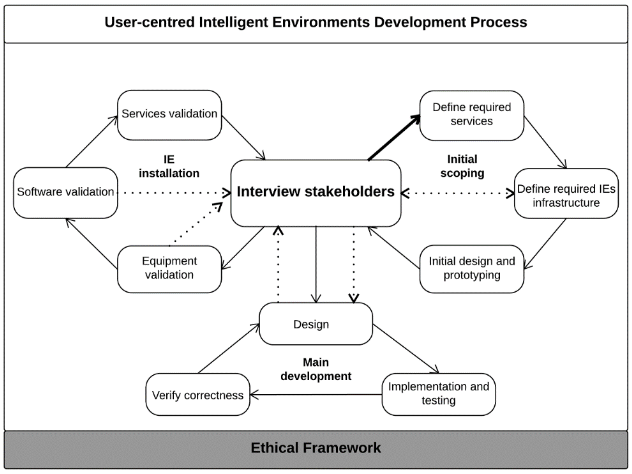

Fig 1. Overview of the User-Centric IE Development

3. The POSEIDON Project

The project POSEIDON (PersOnalized Smart Environments to increase Inclusion of people with DOwn's syNdrome), focuses on the task of bringing some of the latest technological advances to increase inclusion in our society of a specific group of citizens: people with Down's Syndrome (DS). It tries to answer questions posed in the AAL community before about inclusion and the role of AAL beyond the current focus on supporting independence for the elderly (Augusto et al., 2013b).

People with Down's Syndrome have certain characteristics which include areas of strength, areas of weakness and within those features which may be statistically preponderant amongst them, there is also a huge diversity and range of skills (Fidler (2005); Jarrold et al., (2006); Brigstocke et al., (2008); Courtney et al., (2012)). Our project aims at giving priority to their preferences to create technology that is appealing and useful to them. People with DS (along with their relatives and other potential users) were given the opportunity to co-design a solution along the project and we believe this increased the chances of producing a solution which is really useful for the intended beneficiaries. We gathered the direct participation of companies, research centres and Down's Syndrome Associations primarily from Germany, Norway, and the UK. However, the consortium also gathered the opinion and attracted participation of other EU countries. The overarching goals were achieved by empowering first and foremost people with DS. However, support is also available to those who interact with them on a daily basis (family, carers, friends, and service providers). Although there are some technological products in the market, these are very limited and specialised on narrow services, without integrating and leveraging all the potential available by today's technology and expertise. Some of the challenges people with Down's Syndrome face are:

- Access to education and support provided is limited
- Fewer opportunities to find employment
- Difficulties accessing and maintaining social networks
- Sedentarism can result in health problems
- Public information is often in formats that are not easily accessible (e.g. bus timetables)
- Reading and writing can be more difficult

POSEIDON aims to provide a technological infrastructure to foster the development of services which can support people with Down's Syndrome and, to some extent, also those who interact with them on a daily basis. The infrastructure is illustrated with the creation of a system providing services supporting inclusion based on static and mobile smart environments to empower people with DS in different daily life situations. These services provide evidence and guidance on how technology can help people with DS to be more integrated within their society through education, work, mobility and socialization.

This project cannot eradicate all of the problems that people with DS may experience; however, POSEIDON will provide an added layer of support that will facilitate their immersion in usual daily life activities as most of the population experiences it. The project is creating extra support for people with DS. POSEIDON offers information and guidance to encourage decision-making and independence. This is achieved through devices which will provide the infrastructure for a Smart Environment and software which provide the Ambient Intelligence needed to guide them and support them on interacting with the complex real world. Part of these Smart Environment and Ambient Intelligence is available in the market and part is created new specifically to support people with Down's Syndrome or those with similar preferences and needs. There are static devices used at specific locations, for example at home, school or work, whilst the users also have access to the inclusion services everywhere and all the time through mobile computing. Although the main users are people with DS but their family, school teachers, employers, bus drivers, and other people interacting with them are also able to use the static and mobile devices with different interfaces and benefits. Some recent services built as part of POSEIDON have been reported by Kramer et al., (2015) and Covaci et al., (2015).

Each individual is different but overall citizens with Down's Syndrome may require some level of extra support in a variety of situations. We cannot address all possible situations in this project but we considered a few which are related to some of the core challenge areas they face: education, socialisation, wellbeing, and mobility. User-centredness is paramount for the success on adoption of Intelligent Environments and this is even more important in a system like POSEIDON where there is little done before for the intended users, and not much is really known about their interaction with technology. Hence stakeholder involvement was something which drove the project from the earliest stages. Our project considered different types of users and stakeholders as depicted in Table 1.

Table 1: Different types of POSEIDON stakeholders

<table>
<tr><th colspan="2">Stakeholder Categories</th></tr>
<tr><td>Primary Users (PUs): People with Down's Syndrome</td><td rowspan="3">Other (O): those interested in the system but no direct users, e.g., local authorities, user-related organizations, companies developing services, field experts.</td></tr>
<tr><td>Secondary Users (SUs): Main carers (e.g., relatives or social workers)</td></tr>
<tr><td>Tertiary Users (TUs): other system users (e.g., teachers, bus drivers)</td></tr>
</table>

The project consisted of four major iterations, which included three intermediate significant prototypes before the final products are generated at the end of the project. Two of these prototypes were validated through extensive project pilots. Table 2 succinctly explains the salient features of each prototype.

Table 2: Prototypes in POSEIDON

Pr.	Product Development
1	Initial context-aware services, initial apps (e.g., navigation), initial interfaces, first interactive table.
2	Increase quantity and quality of: context-aware services, apps (calendar and improved navigation), interfaces, and interactive table. Initial Development Framework.
3	More mature Development Framework, more apps (e.g., money handling) and improved overall system (esp. HCI acceptance and reliability).

Development was underpinned by a Development Framework, that is methodologies and tools assisting specific tasks (e.g., gathering requirements and supporting context-aware development). These methodologies and tools will be reported in detail in other publications. The focus of this paper instead is focused on the overarching IE creation strategy and the role of stakeholder in co-creation. The intensity and type of user engaging activities is explained in section 4 and how these affected the project development is described in section 5.

4. Stakeholders Involvement in POSEIDON

Technology design needs to consider a set of cognitive and physical abilities to achieve optimal performance. A 3D representation of a real environment might fail to communicate effectively to people who do not have the ability to abstract concepts and worlds. In order to upgrade the lives of some, technology has to be designed for diversity and ability. In developing useful technology, there are several phases to consider: design, development, testing and publishing. Usually, the stakeholders are just considered in the testing phase. However, when the aim is to increase independence of people with cognitive disabilities, a continuous involvement of both, developers and stakeholders, is necessary for creating more relevant products.

A successful product, which people with DS can benefit from, is based on iterations that lead to a refinement of the functionalities and design. Because of the varying range of capabilities and difficulties of the target population, developers need to maintain an updating loop of the proposed solution, in which they consider the feedback of a significant number of stakeholders. In POSEIDON we used U-CIEDP, an iterative co-design methodology that brought together all the involved stakeholders (primary users, caregivers, therapists and developers). We involved stakeholders through a variety of activities (see Table 3). These include questionnaires, interviews, project pilots, workshops with primary and secondary users as well as with the Project Advisory Committee. Initially, we wanted to understand and be able to conceptualise the needs and specific issues of the stakeholders. Then, we produced solutions that address the observations we made in the first step.

To validate the design and content of our proposed system, we asked stakeholders to use and experience it. All these sessions were analysed in detail in aspects related to functionality, user interaction, and quality of experience. Each interaction of the users with our system brought new insights about our stakeholders through this analysis, but also through the provided feedback.

It is important to highlight that the organisation of the different events which facilitated interaction or gathering of feedback from stakeholders were organised mostly following the lead of the Berlin Institute for Social Research (BIS), one of the partners of the POSEIDON project. Although the type of interactions to have, their frequency and their timing were planned and agreed with most of the partners of the project, BIS provided the protocols of interaction with the stakeholders, especially the documents, including surveys, to use when presenting and gathering information from stakeholders (Schulze and Engler, 2016; Schulze and Zirk, 2014).

4.1 Questionnaires/Interviews

The aim of this phase was to assess the requirements of people with DS and to bring up any significant issues that need to be addressed. The requirements analysis was done using different methods: questionnaires (people with DS and caregivers) and face to face interviews with the stakeholders. BIS conducted an initial web-based questionnaire to almost 400 parents, from three different countries. The answers were used to analyse the type of technologies people with DS use, the level and type of support they need when interacting with these technologies. Additionally, focus was put on their living situation to identify how they travel, manage time, handle money and communicate. All this information was used in proposing a set of scenarios and personas that were meant to illustrate the aspects targeted by. The scenarios presented characteristics and possible daily activities of people with DS from different countries.

Table 3: User Engagement Activities during POSEIDON

ID	Type of Involvement	Month Number	No. of Main Stakeholders involved
W1	Workshop	2	5 PU 5 SU
Q1	Questionnaire	2-4	400 SU
W2	Workshop	10	5 PU 7 SU
A1	Advisory Committee	12	3 TU/O 4 SU
W3	Workshop	14	13 PU
P1	Pilot 1	20 - 23	9 PU 9 SU
P2	Extended Pilot	25	26 PU
A2	Advisory Committee	26	3 TU/O 5 SU
P3	Pilot 2	31	9 PU 9 SU

4.2 Workshops with Stakeholders

The first project workshop took place at the beginning of the project. Different technological solutions were presented to the primary users (VR games controlled through Wii control, mouse/keyboard or tablet). The aim of this interaction with people with DS and caregivers was to explore user engagement with different technologies and their quality of experience.

These initial observations were used to create a mock-up of the system with a set of proposed interaction methods. This first prototype was introduced to the users during a workshop that took place in Mainz, Germany in month 8 with participants from 5 countries. We conducted a set of experiments with PUs over 2 days with the intention of assessing: the usability of our first prototype, the advantages and disadvantages of using specific proposed technologies.

This workshop was followed by a series of shorter workshops (half a day long), held primarily in London, additional ones also in Germany and Norway. These events were meant to facilitate the design of the product's functionality and interface. Developers participated in these meetings in order to gain a deeper understanding of the necessary modifications.

Additionally, there were complementary workshops with the Project Advisory Committee, a group of experts which provided useful insights by sharing their expertise, and also a quality check.

4.3 Project Pilots

Over the course of the POSEIDON project, there were two pilots of one month each, and a single day extended pilot. These pilots were carried out in the UK, Norway, and Germany. During the month long pilots, three families from each of the countries were selected to participate in the evaluation.

The process involved screening of potential families through a questionnaire, to check on their suitability for the pilot. Once the families were selected, users were given diary sheets, as a way of documenting their use of the POSEIDON system. Main topics were: who used it, what they liked and did not like. Each family received four visits. In the first visit project developers and Down's Syndrome Association (DSA) monitors went to get to know the families, establish a good relationship with both PU and SU. Information sheets, and consent forms were distributed and completed. Following this, the Home Training of Navigation Services application, POSEIDON Mobile application, POSEIDON Context Reasoner and Carer's web were installed and setup for the users. Over the course of the pilot, different interviews, and questionnaires were completed to gain feedback of the different systems. Moreover, usage of applications was logged, which allowed us to see how many times the users used each component of the system and how they benefitted from it.

For the extended pilot, in a similar fashion, different day events were held in all three countries. A total of 26 people with DS took part with 10 in the UK, 13 in Germany, and 3 in Norway. During the extended pilot there were three items we wanted to evaluate: new functionality added to the different systems including more contexts being handled in the POSEIDON mobile application, a new learning and assessment mode in the Home Training of Navigational Services, and further tests of the Money Handling application.

Our method of co-design based on continuous feedback from the stakeholders allowed developers to maintain a strong connection with the stakeholders and to gain a better understanding of the way primary users interacted with different features.

5. Service Refinement and Evolution

The U-C IEDP method is based on several small and big project iterations and frequent interactions with stakeholders. In this section we explain how the POSEIDON concept, in the form of successive prototypes, was being shaped through the different stages of the U-C IEDP method. The project was planned in three main iterations leading to three evolved version of a system prototype. Table 4 provides a summary of the activities.

5.1 Prototype One

5.1.1 P1 - Initial Scoping

As central to all the main loops in the U-C IEDP, we started gathering the expectations of the stakeholders. Initially, this happened in the form of a questionnaire (Q & U1) to people with DS and their parents. This gave the team feedback about the activities to support. It was found that the participants were often quite capable of carrying out different tasks, including navigating, if with some support. It was felt that areas of achievable tasks with assistance were likely to be a more successful target of development. The first workshop (W1) covered the stages "Define Required Services" and "Define required IE infrastructure" from the U-C IEDP. The technical teams translated the information gathered from the stakeholders into services that were useful for them, during the first workshop. Developers proposed a set of services to support the main activities in which people with DS required help, according to the questionnaire. The questionnaires were also discussed to determine the most suitable technology for people with DS and their parents, selecting the devices and interfaces that materialised the IE. Finally, a requirements document was produced, as a contract between all the stakeholders, defining what POSEIDON would do. After the first workshop, the teams prepared the initial design and started preparing the first prototype. Based on related work, developers mocked up a potential future state of the system.

5.1.2 P1 - Main Development

This first design was discussed in a technical meeting in month 5 with initial ideas. The teams gathered both feedback and suggestions from the national Down's Syndrome Associations based on these ideas. Based on this feedback, the development teams identified areas that needed to be refined, defined and clarified. In the second workshop (W2), the developers introduced a mobile navigation system, using Google Directions for route data. This data was supplemented with photos of the specific Google waypoints, in an effort to see if photos helped them navigate. A racing game was also developed for use with a large smart table, as a way to assess the participant's motor skills, and whether they find the interaction device enjoyable to use.

5.1.3 P1 - IE Installation

The second workshop also covered the whole "IE Installation" loop of the U-C IEDP. The users were instructed on how to use the system. The event was held in Mainz, Germany including 5 people with DS. Some of the feedback highlighted the need of considering time management. During the second workshop, the prototype was tested in order to gather feedback about the Primary Users using the devices. It was found that using automatically generated directions from services including Google Directions did not give sufficiently understandable directions for navigation. Based on this finding, it was decided that secondary users should have the ability to decide their own routes, using their own decision point photos, and textual commands. Using textual commands, the secondary users can generate additional information that can be useful to the primary user including what side of the road to be on, whether to cross at particular places etc. It was found also that the PUs enjoyed using the smart table touch device as an interface device.

5.2 Prototype Two

5.2.1 P2 - Initial Scoping

As input for the "initial scoping", during the interview to the stakeholders, the families presented daily activities of primary users with an emphasis on areas where they need more support.

5.2.2 P2 - Main Development

For prototype two a number of changes had been added to the POSEIDON system. First, routes for the user could be designed in the Home Training of Navigation Services application by the secondary user. This allows secondary users to tailor the routes by adding custom waypoint instructions, and photos to assist the primary user. These routes are then synchronised to the main

POSEIDON application using POSEIDON web services. Other developed services include a specialised calendar service which allows the user to keep track of their events, and add additional data to events including linking personalised routes. A website for use by the SU was created, named Carer's web. On this site, the carer can view where the PU is, alter POSEIDON personalisable features, and also edit calendar events. Other developed services include a context reasoner, which can determine different contexts to assist the user in the main POSEIDON application, including weather information on navigation destinations. Lastly, a game for practicing money handling was created for the primary users, which paired with a smart table.

5.2.3 P2 - IE Installation

Prototype two was tested during Pilot 1 and Extended Pilot 1 (P1). There were technical difficulties with using the smart table in the participants' houses. As it proved too difficult for the families to use without technical supervision, it was not used. The calendar functionality was overall positive, however some PUs required their SUs to input the events due to impaired literacy skills. The main POSEIDON mobile application was viewed as promising and useful. There was feedback that there were some concerns regarding safety, similar to those reported in Kramer et al (2015). It was decided that additional steps should be addable to a route, instead of just editing the Google given instructions. The PU and SUs were positive about the use of context-awareness to drive different notifications to the user including if specific clothing was necessary based on weather conditions.

5.3 Prototype Three

5.3.1 P3 - Initial Scoping

Questionnaires from Pilot 1 were used as the first stage of the initial scoping in the U-C SDP, "Interviewing the stakeholders". During pilot 1, users demanded more personalisation possibilities when defining a route (due to insufficient number of decision point provided by google directions). Also, they demanded some other features for ensuring the wellbeing of the primary user, e.g., when s/he gets lost. Taking this feedback, the developers redefined the required services to have a new approach for route creation: secondary users take photos of the routes in the streets, and they are automatically translated into a route by using the GPS coordinates from the place they were taken. Following this, developers created the definition of the infrastructure, by adding new context awareness. The creation of new contexts was complemented by a questionnaire conducted to 130 families that have children with DS. Two new contexts were identified: "When the primary user is standing still for a long time" and "when the primary user needs assistance with the navigation". Finally, the initial design for the final prototype began.

5.3.2 P3 - Main Development

For prototype three, an improved version of the POSEIDON navigation application was introduced. In this application, further improvements to navigation and calendar handling were included. An application for creating routes was developed for mobile devices. This was due to added complications in making the user create the routes on a static computer at home. With the route creator application, the SU can walk the intended route, taking photos, and automatically tagging decision points with their current location. Money handling assistance has been improved, by the creation of a mobile application, which the user can take with them to local shops for purchasing various goods. It allows them to not only practice picking the correct money for particular items, but can also assist them in notifying them how much money they need to take, and what money denominations are required to pay for a particular shopping basket. Additionally, the context reasoner provided in the previous prototype has been extended with personalisable contexts, allowing different context settings to be tailored to suit the user. An updated version of the Home Training of Navigation Services was developed to include the ability to add new decision points to routes, add voice commands, and further assessment modes to allow the PU to train a route more. Finally, the online Carer's web included more personalisation features, the inclusion of Money handling to let the SU setup shopping lists for use with the mobile application. Lastly a new querying service based on previous events allows the PU and SU to compare how well they have navigated previously over different time windows.

5.3.3 P3 - IE Installation

Prototype three was tested during the final Pilot 2 of the project. During Pilot 2 (P2), developers guided users to learn how to use the POSEIDON ecosystem. The pilot was used to validate the equipment, software and other services. In all, pilot participants appear to find the vision for POSEIDON applications a good idea. This generally led to high motivation by participants at the start of the pilot. Over the course of the pilot, there were indications of users favouring particular services, especially the application for route making, and main navigation application. Particularly, secondary users enjoyed the ability to easily customise the route with their primary users, adding photos, and customised instructions.

Calendar services were considered a usable feature by some participants. Because many participants are often very busy with a lot of different activities, they enjoyed using the service instead of a hand written diary. Secondary users also gave positive feedback for the ability to monitor how well the primary user navigates using the learning module.

Feelings towards services to improve money handling were slightly more strained. While there was positive feedback regarding the applicability of such a service, it was a service that users most struggled to use. This appeared to be a combination of issues including how intuitive it was, and early teething problems when it was deployed. For example, some users appeared to struggle with setting up the system: adding the different items, prices, and calendar event for the shopping journey.

Towards the end of the pilot, to encourage the use of all the services, an integrated scenario was devised. This scenario involved the primary user going to a supermarket to go shopping. To achieve the scenario, the secondary user would need to prepare the route, create a shopping list on the carer's web, and setup a calendar event. These scenarios were completed with issues, which largely were with the money handling application.

Overall, we believe the pilot was a positive experience, however it was observed that the participants many have underestimated the amount of time regarded to learn to use the new services. We also found some motivational issues in the second half of the pilot. Part of this motivation was caused by some participants having smart phones already, and not wanting to use the test devices in addition to their phones. This could have created a barrier to users using some of the available services to them.

Table 4: Relation between the U-C IEDP stages, event types and products in the POSEIDON project

U-C IEDP Main Loop	U-C IEDP Secondary Loop	Prototype 1		Prototype 2		Prototype 3	
		Event Type	Outcome	Event Type	Outcome	Event Type	Outcome
Initial Scoping	Interview Stakeholders	Q U1	Feedback about important activities to support, 'way finding' considered fundamental. Development Framework outlined.	U3	Families presented daily activities of primary users emphasizing where they needed more support. Importance of Calendar and money handling identified.	Q U5	a) routes created automatically based on photos GPS coordinates b) Improve HNS feedback modes. Devel. Fr. revised.
	Define Required Services	W1	A set of services to address the suggested activities. Emphasis in safety.	A1	Emphasis on health issues.		Need to replace Google Directions
	Define required IEs infrastructure	W1	The initial infrastructure consisted of stationary and mobile computing and VR.	A1	Given preference to equipment and interfaces which help PUs sight		Issues with the use of interactive table
	Initial design and prototyping		Developers gathered first potential components, HCI mock ups, and virtualisations.	A1	Navigation system should give more emphasis to sight		Alternative route handling with Google MyMaps
Main development	Interview Stakeholders	U2	Feedback on first navigation support services is reviewed	U4	Validation of real-world imagery and context of places.	U6	Need for better customisation of routes
	Design I		First navigation exercises designed	W3	Mixed reality solution analysed	A2	Lack of wayfinding apps
	Implementation and testing		Initial testing done in labs	W3	Navigation with customized metadata	A2	Created customised routes
	Verify correctness		Problems detected with the usefulness of routes provided by Google maps	W3	No metadata for some GPS points	A2	Problems with public transport Identified
	Design II		More clear strategy in complement of VR at home and mobile services outdoors	W3	Design of games to assess user knowledge of routes	A2	Check overall prototype with ethical framework
IE Installation	Interview Stakeholders	W2	PU confident of learning how to go to a new destination using HNS based on real world imagery. Suggesting importance of time management.	P1	Lack of route personalization possibilities (insufficient decision points provided by google directions) leads to new approach to create routes based on GPS coordinates of photos	P2	Product was well received overall. Calendar reached maturity. Development Framework more mature.
	Equipment Validation		Increased focus on the phone; add audio guidance. Issues of PUs matching real world imagery and virtualisations	P1	Interactive tables presented challenges to configure and use. Issues with computer versions.	P2	Interactive table was not used. Focus on home training and outdoor apps
	Software Validation		Delay showing the customised information	P1	Improve assessment modes of training for navigation. Importance of a mobile app for handling money.	P2	Issues with money handling app.
	Services Validation		Lack of accuracy in directions provided by Google leads to personalised directions	P1	Issues with Google Directions accuracy	P2	Specific personalisation options identified

6. CONCLUSIONS

We report on the application of the User-Centred Intelligent Environments Development Process (U-C IEDP) to support the co-creation of a system which fosters inclusion of individuals with special needs into society.

The project exercised the U-C IEDP methodology in several ways, both through its micro and macro loops. Core to the method used is the frequent interaction of developers with stakeholders. We provided details of the nature of these interactions, their relation to the different stages of U-C IEDP, and also of their effect in the services being produced. This has kept the specific related user groups informed of the evolution of the project. It has allowed different project stakeholders to be involved in different iterations until each of them has secured some level of benefit from the project. For example, primary and secondary users have voiced needs, preferences and concerns, and the companies involved are more confident their product will be satisfactory for the intended market niche. Developers are more reassured their work will be well received and useful.

The application of the methodology was overall successful fulfilling the needs of a diversity of stakeholders and flexibility to adopt promising options appearing at different stages and to side-line others when the evidence was not favourable.

This methodology requires stakeholders willing to engage and developers with capacity to listen. This can be achieved in various degrees of intensity according to the characteristics of the project, however the ethos is that given the complexity of the technology considered and the potential impact in people's lives, it is better to avoid surprised so stakeholders should be kept somehow in the loop at key stages.

Specific tool support is still lacking and developing tools which can help automating and tracking the different stages will help to apply this methodology more efficiently. This is one of the main current objectives in our research group.

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8. REFERENCES

[1] Alegre, U., Augusto, J.C., Clark, T., 2016. Engineering Context-Aware Systems and Applications: A survey. *Journal of Systems and Software* Vol. 117, pp. 55-83. Elsevier.

[2] Augusto, J.C., Huch, M., Kameas, A., Maitland, J., McCullagh, P., Roberts, J., Sixsmith, A., Wichert, R. (eds.) 2012: *Handbook of Ambient Assisted Living*. AISE Series, vol. 11. IOS Press.

[3] Augusto, J.C., 2012: AAL4DS(Can AAL Technology Help People with Down's Syndrome to Live Better Lives?). In: *Proceedings of AALForum 2012*, Session 'Social Innovation: Connecting the Dots...', Eindhoven, The Netherlands.

[4] Augusto, J. C., Callaghan, V., Kameas, A., Cook, D., Satoh I., 2013. Intelligent Environments: a manifesto. Human-centric Computing and Information Sciences, 3:12. Springer. URL: http://www.hcis-journal.com/content/3/1/12

[5] Augusto, J. C., 2014. A User-Centred Software Development Process. *Proceedings of the 10th International Conference on Intelligent Environments – IE'14*. Shanghai, IEEE Press.

[6] Brigstocke, S., Hulme, C., Nye, J.: Number and arithmetic skills in children with Down syndrome. *Down Syndrome Research and Practice* (2008), http://www.down-syndrome.org/reviews/2070/reviews-2070.pdf

[7] Corno, F., Guercio, E., De Russis, L., Gargiulo, E., 2015. Designing for user confidence in intelligent environments. *Journal of Reliable Intelligent Environments*. Springer International Publishing Switzerland.

[8] Courtney, T., Pahl, J., Karrim, S., 2012. Employment in Down Syndrome. In: *Proc. of 11th World Down Syndrome Congress*, Capetown, South Africa.

[9] Covaci, A., Kramer, D., Augusto J. C., Rus, S., Braun A., 2015. Assessing Real World Imagery in Virtual Environments for People with Cognitive Disabilities. In: *International Conference on Intelligent Environments*, Prague, Czech Republic.

[10] De Russis, L., 2014. *Interacting with smart environments: users, interfaces, and devices*. PhD thesis, Politecnico di Torino. doi:10.6092/polito/porto/2536887

[11] Fidler, D.J. 2005. The Emerging Down Syndrome Behavioural phenotype in *Early Childhood: Implications for practice. Infants and Young Children* 18(2), 86–103, http://depts.washington.edu/isei/iyc/fidler_18_2.pdf

[12] Jarrold, C., Purser, H., Brock, J., 2006. Short-term memory in Down syndrome. In: Alloway, T.P., Gathercole, S.E. (eds.) *Working Memory and Neurodevelopmental Conditions*, pp. 239–266. Psychology Press, Hove.

[13] Jones, S., Hara, S., Augusto, J., 2015. eFRIEND: an Ethical Framework for Intelligent Environment Development. *Ethics and Information Technology* (Springer Verlag), Vol 17, issue 12, pp. 11-25, Springer.

[14] Kramer, D., Covaci, A., Augusto J. C., 2015. Developing Navigational Services for People with Down's Syndrome. In: *International Conference on Intelligent Environments*, Prague, Czech Republic.

[15] Pennings, L., Veugen, T., de Korte, A., 2010: When are intelligent sensor environments successful? *Technol. Soc.* 32, 197–203.

[16] Schulze, E., and Engler, A. (2016). POSEIDON – Personalized Smart Environments to Increase Inclusion of People with Down's Syndrome – Results of the first and the extended pilot study. To Appear in Proceedings WISHWell'16, London.

[17] Schulze, E., and Zirk, A. (2014). Personalized Smart Environment to Increase Inclusion of People with Down Syndrome. Results of the Requirement Analysis. In: Miesenberger, K. u.a. (Eds.) Computers Helping People with Special Needs. 14th ICCHP 2014, Springer, p. 144-147.

[18] Weiser, M., 1999. The computer for the 21st century. Mobile Computing and Communications Review 3(3): 3-11.