Transdisciplinary Engineering Methods for Social Innovation of Industry 4.0
M. Peruzzini et al. (Eds.)

doi:10.3233/978-1-61499-898-3-763

Architectural Knowledge Integration in a Social Innovation Context

John P.T. MO[a,1] and Ronald C. BECKETT[b]
[a] *RMIT University Australia*
[b] *Swinburne University of Technology Australia*

Abstract. In an earlier study we had noted that the term transdisciplinary is used in describing a number of different situations, but always implied some form of knowledge-sharing collaboration. Researchers have observed that the requisite knowledge lies both within a development team and outside of it, but how it all works in harmony may vary from case to case. In this paper we explore the utility of a system architecture description standard, ISO 42010 as a framework for representing architectiral knowledge in a consistent way. This is illustrated in a social innovation case study. The case also illustrates how knowledge from social, medical and physical sciences was combined at multiple levels within a telemedicine delivery system.

Keywords. Transdisciplinary, knowledge, architecture, social innovation

Introduction

Beckett and Vachhrajani [1] had noted that the term transdisciplinary is used in describing a number of different situations: in research, development and deployment settings, but some form of knowledge-sharing collaboration, was common to all. Two underlying themes relating to transdisciplinary innovation were identified, one being the value of network thinking and interface protocols to facilitate making multiple connections, and another being the need to unify different transdisciplinary knowledge elements, working out how the all fit together.

Tallmen et al [2] examined knowledge flows within and between firms, differentiating the influence of architectural knowledge and component knowledge. They viewed architectural knowledge as an understanding of a system of knowledge or organisation (e.g. who knows what and where to find them), and component knowledge as an identifiable element of a body of knowledge. We contend that architectural knowledge - how things fit together is particularly important in a transdisciplinary engineering environment.

In this paper we explore the development of a socio-technical system by one firm addressing social problems associated with hearing impairment that required both community engagement and technological contributions. We explore the utility of a system architecture description standard, ISO 42010, in framing systems knowledge associated with this case. We start with consideration of the social problem.

[1] Corresponding Author, Mail: john.mo@rmit.edu.au.

1. The Social Issue of Hearing Impairment

Arlinger [3] reviewed the negative impact of uncorrected hearing loss, noting that problems in recognizing speech, especially in difficult environments, give rise to the largest number of concerns. Wesendahl [4] suggested that whilst up to 20% of all Germans may experience some hearing loss, less than 25% of those use hearing aids. They reckoned that the stigma of wearing hearing aids, an unsatisfactory solution in contrast to the marketing promises of the prescribed device, the quality of fitting in artificial conditions rather than in real soundscapes, and the price were some of the important reasons for these circumstances.

In 2010 the US National Institute on Deafness and Other Communication Disorders and the National Institute of Health jointly sponsored a research working group on accessible and affordable hearing health care for adults with mild to moderate hearing loss. It was suggested by Donahue et al [5] that factors influencing accessibility and affordability were seen as:

- Changing demographics, with an ageing population increasing the proportion of the population with hearing problems Knudsen [7] noted a increase in the number of research papers dealing with this subject)
- Changing socio-economic conditions, with many groups being economically disadvantaged and under-served
- Changing technologies, including automated auditory assessment, reduction in hearing aid component costs, fitting programs run on P-Cs, and possibilities for more compact packaging. Knudsen [7] also noted an increase in the number of research papers dealing with this subject)
- Changing service delivery paradigms such as store-front sales (e.g. Costco) and internet sales, telemedicine opportunities for testing and fitting

Donahue et al [5] further noted that some professional concerns related to the educational qualifications to make diagnoses and undertake device fitting. These factors were also recognised by Dalton [6].

Mohr et al [8] noted the significant societal cost associated with hearing loss, that a person can become socially isolated, be more at risk because audible warnings are not heard, and be less productive in the workplace. It has been suggested that sensory decline in older adults, including hearing difficulties, challenge comprehension and memory for everyday speech, and that depression, anxiety, lethargy and social dissatisfaction are often reported. Wallhagen et al [9] noted that a spouses hearing loss also impacted their partner’s physical, psychological and social well-being.

In summary, there are social and economic arguments for increasing hearing aid uptake, and scope for technical improvement to be integrated in both providing a total solution and overcoming some potential barriers.

2. The Hearing Enhancement Journey

A solution offered to hearing-impaired people is some combination of technology (a hearing aid) and support services. Input conditions are shaped by the patient’s perceived hearing capability and associated acoustic environments. The desired output is an enhanced patient sensing and discrimination capability. Practical experience also suggests there are two other possible outcomes: rejection of the opportunity to participate at some point (e.g. on cost grounds) or the abandonment of a particular solution after an initial trial period (e.g the hearing aid is too difficult to use). A representation of functional activities pursued in search of enhanced hearing is outlined in Table 1 as a sequence of events.

Table 1. Key Events in the Hearing Enhancement Journey (adapted from Beckett, Saunders and Blamey, [10]).

Event	Activities
1. Recognition of hearing impairment	This commonly involves consideration of the patient's social and work environment and some form of screening. The outcome may be a medical referral and/or a personal decision to seek a more detailed assessment
2. Assessment of hearing impairment	This involves one or more tests where quantitative and qualitative medical data is collected. The outcome at this stage is the identification of impact factors and possible future actions, one of which may be a decision not to proceed further
3. Enhancement solution identification	This commonly considers cost-benefit tradeoffs and some experimentation with options, but the outcomes may be the selection of a particular hearing aid or a decision not to proceed further
4. Enhancement solution implementation	This involves fitting and tuning the hearing aid selected, and the outcome is a functioning hearing enhancement capability
5. Solution refinement and patient learning	This involves learning about the practicalities of using and tuning a hearing aid in a variety of day-to-day situations. Outcomes may be the regular use of the device, the occasional use of the device, or the abandonment of its use.
6. Ongoing review and adjustment	This involves monitoring patient progress, routine re-assessment, and consideration of technology advances. The outcome may be a decision to acquire a different kind of hearing aid

The most common way of providing support is to have a patient undertake a simple frequency response test at an audiology clinic which shows where degradation should be compensated for. Then a hearing aid, tuned to suit this profile is sold to the patient in a package deal that includes ongoing support and tuning. The hearing aids are produced by specialist manufacturers, and the audiology laboratory clinic acts as their sales agent. The package deal can be quite expensive, and some patients may have difficulty in attending a clinic for either the initial testing, subsequent fine tuning of the hearing aid or both.

3. The Research Approach

In this paper we briefly explore how one company sought to provide a complete systemic solution, linking all events in the hearing enhancement journey (Table 1) using smart hearing aid technology and an on-line business model to reduce costs. We adopt a qualitative longitudinal case study approach, as according to Yin [11] a case study methodology is appropriate when investigating questions of 'how' using rich data sets. The prior discussion suggests a need to consider the concerns of a number of stakeholders and some matters of social,technological and economic context in seeking an intergrated solution. We chose the ISO/IEC 42010 architecture description framework to represent our case description and include consideration of associated knowledge aspects. Some background and rationale follows.

3.1. The ISO/IEC 42010 Framework

ISO/IEC 42010:2007 - *Systems and software engineering — Recommended practice for architectural description of software-intensive systems* (represented in Figure 1) originated in a software development environment. It includes consideration of environmental and stakeholder influences, and supports the idea of combining multiple views that may be informed by models. The central theme is the linkage between stakeholders, system architecture and rationale. The rationale component is intended to capture decisions made in system development to inform those that may subsequently operate and enhance the system. Section 4.4 of the standard indicates it may be used for a number of purposes, including "Review, analysis, and evaluation of the system across the life cycle", and this is the context we are considering here in relation to the hearing enhancement journey illustrated in Table 1. In the following case study description, we use the main topics of Figure 1 to outline attributes of the case as a complex system.

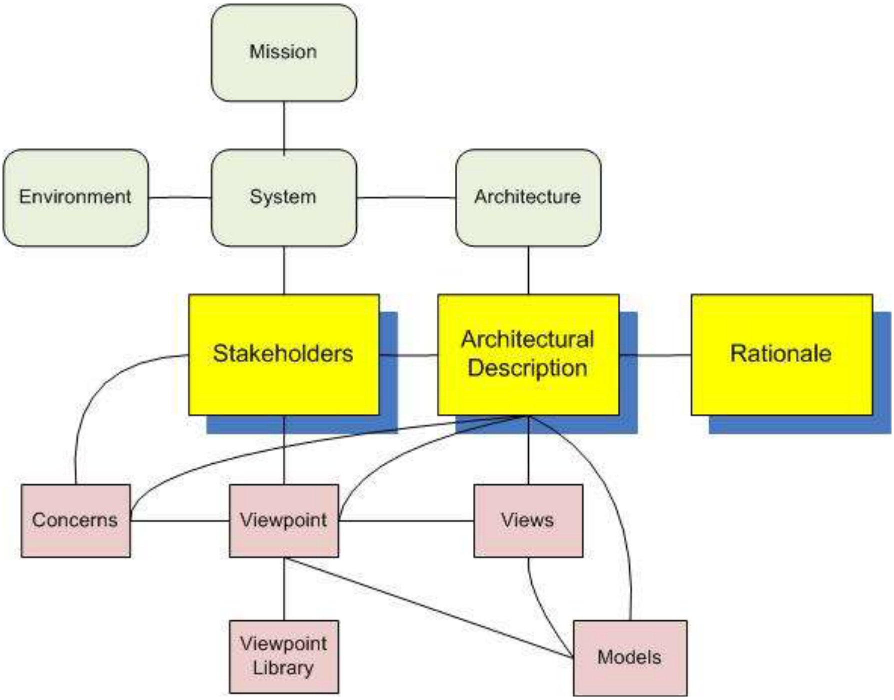

Figure 1. A representation of the ISO/IEC 42010 Framework

3.2. Identifying Multi-disciplinary Knowledge Elements

The ISO standard also indicates that, to understand a complex system, it is necessary to observe the system from multiple viewpoints. A viewpoint is defined as "A specification of the conventions for constructing and using a view. A pattern or template from which to develop individual views by establishing the purposes and audience for a view and the techniques for its creation and analysis." In this paper, we are adopting a knowledge oriented 'template', which is based on the observation that two kinds of knowledge are needed to operate a coherent system (Beckett [12], Tallman et al [2]):

- Domain knowledge about the physical, information and decision subsystems that work together. This triad is consistent with the underpinnings of industry 4.0 where inexpensive smart sensors - physical devices - produce data that can ultimately be utilized in support of machine or human decision-making.
- Architectural knowledge about how these subsystems work together and how a particular system links with other related systems

4. The Case Study: Blamey Saunders Hears

Blamey Saunders Hears (BSH) offers on-line hearing enhancement solutions. The researcher founders first registered a company in 2007 in response to deficiencies observed in traditional technology diffusion and application pathways. They allocated minimal effort to product promotion in the first few years as the focus was on Beta testing with initial clients in an agile project management style to refine the front office engagement and back office support infrastructure. Experience with online customer engagement practice was pooled with that of an associated firm, America hears, that was also selling hearing aids on-line. The organisation was initially hosted at the Bionic Hearing Institute in Melbourne, Australia, where the founders had worked on cochlear implant technology. The Institute is close to an Eye and Ear Hospital and surrounding specialists rooms – a kind of technology cluster precinct. In 2010, BSH moved to its own premises in the same area, maintaining knowledge-sharing connections with expertise from multiple disciplines.

The founders of the company, Elaine Saunders and Peter Blamey, are passionate about ending the negative perceptions associated with hearing loss, demystifying the buying process and offering a much fairer deal to all those who need hearing aids by drawing on emergent technology. Elaine Saunders has a background in clinical audiology research and Peter Blamey has a background in digital sound processing research. Both had won international recognition for their work.

4.1. Mission, System, Environment and Architecture (Figure 1)

Contributors to the development and deployment of complex socio-technical systems are orchestrated by a common goal, often expressed in a few words as a **mission** or vision statement. The BSH website espouses - "*Take control of your hearing - our premium hearing aids and award winning technology let you control the sound of your world*". This promotes the idea of health self-management, as practiced in other situations, like the self-management of diabetes. BSH has developed a complete telemedicine **system** including an online Speech Perception Test for measurement of hearing and hearing aid outcomes, hearing aids using patented ADRO technology, and apps for adjustment of hearing aids via a proprietary bluetooth programmer connected to a user device (smartphone, tablet or computer).

The hearing enhancement system, as seen by users is a product-service package where they are in control of its application, and they can reassess their hearing capabilities anytime, anywhere. The **social environmen**t has been discussed in preceding sections of this paper. The transparent background **technological environment** draws on the internet as a communication medium, back office client information management systems, embedded software in the hearing aid, tuning software and the micro-miniaturisation of hearing aid components. The macro-level system **architecture** is aligned with the events and associated functional activities shown in Table 1. It has been observed that clients may decide to disengage at different points along the way (e.g. Knudsen et al [7]). We make the passing comment that having established an architecture this sequence of events could be modelled as a petrinet with transitions/decision points between each event, and sub-tier petrinets associated with each event, as might be appreciated from the viewpoint descriptions presented later.

4.2. Stakeholders, Rationale and Viewpoints (Figure 1)

The **stakeholders** are the founders and funding organizations, BSH development and operational staff, strategic supplier partners, and the clients accessing the services offered and using the product. Whilst BSH designs and sells hearing aids, all manufacturing is outsourced to trusted suppliers that the BSH founders had established collaborations with in their prior research work .

There is reference in the literature to the role of a 'significant other' who may influence the person with hearing difficulty to do something about it, but in a family situation that person may also experience a reduced quality of life (Brooks et al [13]). If a person acquires a hearing aid, a 'significant other' may assist in learning to use the hearing aid and in enhancing their speech interpretation skills via a program of learning (Hickson and Worrall [14]). In an on-line purchase and support situation, it is speculated that a significant other may help by providing IT skills to facilitate hearing aid setup and optimisation. In the BSH case, they are trialling the idea of engagement with a local pharmacist as a trusted 'significant other' to help provide support in regional centres.

The system **rationale** is founded on addressing several stakeholder concerns:

- about the social impact of hearing loss, and making it easier to be assessed at an early stage,
- about access to an effective hearing enhancement system where users may want to investigate their position from the privacy of their own homes and/or may not find it convenient to visit a traditional audiology clinic,
- about the minitarization of hearing aids to minimize the perceived social stigma of wearing a hearing aid,
- about the ability of a hearing aid to enhance speech perception in various environments,
- about reducing the combined cost of testing, hearing aid purchase and help with tuning plus the ability to continue to take hearing tests with and without the hearing aid.

As outlined in the research methodology, the approach adopted is to use a **viewpoint** 'template' to discuss the knowledge associated with each 'event' in table 1. In this paper, space limitations preclude the consideration of all events, so we illustrate the approach in relation to the first two events.

4.2.1. Knowledge associated with the recognition of hearing impairment event

This is primarily a sociological activity. As for many people, hearing impairment develops slowly, and may be compensated for in the early stages, e.g. by turning up the volume on the TV. It may be seen as a minor inconvenience, so they may not be looking for medical assistance. But as noted earlier, those close to them may notice and be concerned about the observed changes. Therefore, it has not been sufficient for BSH to just advertise the technical virtues of their hearing aids, but it also had to embark on an education campaign via multiple media channels. From a knowledge diffusion perspective physical sub-systems involved include lecture venues, meet and greet venues (e.g. visits to regional pharmacies) radio and TV studios and on-line connections. This requires domain knowledge of how, where and when to best engage, e.g. arranging face-to-face lectures in conjunction with community groups, drawing on the reputations of the founders.to attract an audience.

Information sharing is primarily via a blog site maintained by Elaine Saunders, where user-oriented knowledge is presented in the context of significant events and high profile user endorsements that build reputation, a long list of frequently asked question relating to all aspects of the hearing enhancement journey, and responses to critics of the BSH telemedicine approach. Requisite knowledge of the decision sub-system relates to an understanding of potential barriers to the personal acknowledgement of a hearing problem, and what incentive might stimulate action. Architectural knowledge is represented in an understanding of how multi-media broadcasting, the maintenance of an information system and decision criteria influence each other, e.g what information that could influence a decision might be missing?

4.2.2. Knowledge associated with the assessment of hearing impairment event

This is primarily a technological activity bringing multiple disciplines together. The Blamey-Saunders on-line test requires the client.patient to listen to a word announced via their computer audio system, then type in what they thought that word was.The physical interface is via the computer, and the client/patient is given some trial words and asked to adjust the volume so the words can be clearly heard. This test draws the sound signatures of different words to evaluate what is being understood and what is not.

Background research has shown this method of testing also captures tonal diagnostic dataEach test consists of responding to 50 words drawn from a larger library of words to make each test somewhat unique. The results collected are analysed in the information subsystem using algorithms developed through the combined knowledge of speech recognition and audiology experts to asses both tonal and temporal response characteristics. A decision subsystem forms an opinion about the extent to which a BSH hearing aid may or may not help, and produces a report fed back to the client/patient soon after the end of the test. This requires knowledge about how well any observed deficiency may be able to be compensated for by the BSH device. The data collected is stored in a BSH database, and if the client wishes, this can be copied to a national patient e-health database to form part of the individuals medical history.

5. Discussion

In the case presented here medical practitioners, electronics and software engineers, system integrators, marketing practitioners and clients had to interact in the development and operation of a publicly accessible telemedicine system. Development of the the embedded products and processes could be described as adopting an open innovation / open source strategy where the product elements of the offering evolved over a decade or so through contributions from from researchers in several countries. This multidisciplinary network peovided access to a significant clinical trials database and a platform of technology components that had been approved by regulators somewhere in the world. BSH have established strategic partnerships with a number of enterprises to facilitate advanced technology production. BSH was located in a region where relevant expertise could be accessed.

We suggest that BSH is embedded in a specialist knowledge ecosystem, where linkages are deliberately made at times and places as needed. From a system architecture perspective, the BSH telemedicine system could be regarded as a system of systems, each of which is associated with an event in the innovation journey, with social and/or social or technological subsystems working together within an event. At this level of detail, the component knowledge contributions of the different specialists can be appreciated - marketing and clinical specialists helping clients to recognize hearing impairment; speech recognition, audiologist and software engineers working together on assessment tools.

In conventional management of the events shown in Table 1 there is some partitioning of the events, with the tasks being distributed between different actors. The need for assessment may come from a client GP, or be stimulated by advertising a 'free' tonal test using equipment developed by others. An audiologist may sell and fit a hearing aid developed and produced by a global manufacturer, and offer 'free' post-sales service, but all costs are bundled in the price of the hearing aid. This specialization simplifies the extent of networking required of any actor, but retains a technological focus and may limit knowledge flows and opportunities for innovation.

In reviewing approaches to transdisciplinary research in the health sector, Kessel and Rosenfield [15]observed that "far-sighted [World Health Organisation] medical doctors and international health workers began to realize that the effective delivery of health care, especially in cross-cultural settings, involved sociocultural as well as purely medical factors." What we take from this is that the concept of transdisciplinary innovation involves the melding of social, technological and organisational perspectives oriented towards the needs/wants of the intended beneficiaries

Avgeriou et al [16] observed a shift in focus of the software architecture community towards architectural knowledge. Whilst software architecture played an important role in managing the complex interactions and dependencies between stakeholders and provided a central artifact that can be used for reference, a software system's architecture is no longer perceived as interacting components and connectors only, but also as a set of architectural decisions that convey the architectural principles underlying a particular design. They suggested design practices that fail to document design decisions and their underlying rationale can lead to undesirable consequences such as poor stakeholder communication and poor traceability between requirements, architecture and implementation.

6. Concluding Remarks

In this paper we have drawn on a framework for developing software architecture descriptions (ISO 42010) and we incorporated knowledge – oriented viewpoints to describe a particular telemedicine case. The world of users and the world of system providers were brought together through a mapping of user engagement

We presented a social innovation case - providing an alternative approach to dealing with a widespread health issue. A study of the literature related to the issue drew out a common medical practice - viewing a health management episode as a series of events with decision gates / transitions between them - a form of discrete event analysis. We suggest this form of systemic representation may be useful in studying other opportunities for social innovation. Some events in the case study were managed through human interaction, some involved the use of artifical intelligence that was not evident to the patient, who was only interested in a solution to their problem. The implication here is that mapping functional needs can provide a stable platform even if there is variety in the implementation arrangements.

What did we learn about the utility of the ISO 42010 framework? Firstly, whilst a summary is given here, using each of the elements of the framework to prompt critical questioning in relation to that element stimulated an extensive discussion. Some insight into the extent of this may be gleaned from the summary of the system social **environment** presented early in this paper. If discussion of each element was expanded in this way, we would have a book on the subject. Secondly, introducing a knowledge perspective prompted us to ask additional questions, specifically:

- What are the activities/physical processes at work?
- Who does what to make them happen?
- What information is needed to undertake each physical process?
- What background knowledge is needed to support each physical process? What kinds of technical data have to be managed in the data system?
- What kinds of management/control data have to be managed in the data system?
- What kinds of background knowledge are associated with managing this data?
- What kinds of decisions have to be made, and how is this process supported?
- What kind of data is needed to make decisions?
- What kinds of background knowledge support the decision system?
- What overarching background knowledge is needed to integrate the physical/data/decision systems?

Thirdly, using this knowledge viewpoint to consider each systemic event shown in Table 1 provided unifying insights into where and how transdisciplinary knowledge contributed to system operation. By way of example, at a micr-level, the introduction of a hearing test based on speech required collaboration between clinicians who understood how sound was interpreted, sound engineering analysts could extract different components from the sound signature, and software engineers using artificial intelligence techniques to interpret the extracted data. At a macro-level, the tools developed had to be integrated in an on-line system combining user, product, process and IT expertise.

In comparing observations from the case with those in the literature, we have observed that the term architectural knowledge is used in more than one context by different authors. One represents knowledge of the operational architecture of a system, and another represents the knowledge of how generic subsystems (physical, information and decision) work together. A third use of the term relates to knowledge access - an understanding of the structure of an independent, but potentially linked knowledge network and who knows what. Exploring the different notions of architectural knowledge could be a topic for further research.

References

[1] R.C. Beckett and H. Vachhrajani, Transdisciplinary Innovation: Connecting Ideas from Professional and Community Networks. C.H. Chen et al. (eds.) *Transdisciplinary Engineering: A Paradigm Shift*, IOS Press, Amsterdam, 2017, pp. 737-744.

[2] S. Tallman, M. Jenkins, N. Henry and S. Pinch. Knowledge, clusters, and competitive advantage. *Academy of management review*, Vol. 29, 2004, Issue 2, pp. 258-271.

[3] S. Arlinger, Negative consequences of uncorrected hearing loss-a review. *International Journal of Audiology*, 42(sup2), S17–S20, 2003. doi:10.3109/14992020309074639 PMID:12918624

[4] T. Wesendahl, Hearing aid fitting: Application of telemedicine in audiology, *The International Tinnitus Journal*, Vol.9, 2003, Issue 1, pp. 56–58, PMID:14763332

[5] A. Donahue, J.R. Dubno and L. Beck, Accessible and affordable hearing health care for adults with mild to moderate hearing loss, *Ear and Hearing*, Vol. 31, 2010, Issue 1, pp. 2–6.

[6] D.S. Dalton, K.J. Cruickshanks, B.E. Klein, R. Klein, T.L. Wiley and D.M. Nondahl, The impact of hearing loss on quality of life in older adults, *The Gerontologist*, *43*(5), 2003, pp.661–668.

[7] L.V. Knudsen, Factors influencing help seeking, hearing aid uptake, hearing aid use and satisfaction with hearing aids: A review of the literature, *Trends in Amplification*, Vol. 14, 2010, Issue 3, pp.127–154.

[8] P.E. Mohr, J.J. Feldman, J.L. Dunbar, A. McKonkey-Robbins, J.K. Niparko, R.K. Rittenhouse and M.W. Skinner, The societal costs of severe to profound hearing loss in the United States, *International Journal of Technology Assessment in Health Care*, Vol.16, 2000, Issue 4, pp. 1120–1135.

[9] M.I. Wallhagen, W.J. Strawbridge, S.J. Shema and G.A. Kaplan, Impact of self-assessed hearing loss on a spouse: A longitudinal analysis of couples, *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences*, *59*(3), 2004, S190–S196, doi:10.1093/geronb/59.3.S190 PMID:15118025.

[10] R.C. Beckett, E. Saunders and P. Blamey, Optimising hearing aid utilisation using telemedicine tools. Chapter 7 in Maria Manuela Cruz-Cunha and Isabel Miranda (Eds) *Encyclopedia of E-Health and Telemedicine*, IGI Global, Hershey, 2016.

[11] R.K. Yin, *Case study research design and methods*, Fifth Edition, Sage Publications, Thousand Oaks, 2014.

[12] R.C. Beckett, Determining the anatomy of business systems for a virtual enterprise, *Computers in Industry*, Vol. 51, June, 2003, Issue 2, pp 127-138.

[13] D.N. Brooks, R.S. Hallam and P.A. Mellor, The effects on significant others of providing a hearing aid to the hearing-impaired partner, *British Journal of Audiology*, Vol.35, 2001, No. 3, pp.165-171.

[14] L. Hickson and L. Worrall, Beyond hearing aid fitting: Improving communication for older adults', *International Journal of Audiology*, Vol 42, 2003, No. sup2, pp. 84-91.

[15] F. Kessel and P.L. Rosenfield, Toward transdisciplinary research: historical and contemporary perspectives, *American Journal of Preventive Medicine*, Vol. 35, 2008, No. 2, pp. S225-S234.

[16] P. Avgeriou, P. Kruchten, P. Lago, P. Grisham and D. Perry, Sharig and Reusing Architectural Knowledge--Architecture, Rationale, and Design Intent. In: *Companion to the proceedings of the 29th International Conference on Software Engineering*, IEEE Computer Society, May, 2007, pp. 109-110.