JYU DISSERTATIONS 110

Julia Kantorovitch

Understanding Awareness in Modern Smart Products Design

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF INFORMATION TECHNOLOGY

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“The only true voyage of discovery, would be not to visit strange lands, but to possess other eyes.”

(Marcel Proust. In Search of Lost Time. 1913)

”When we try to pick out anything by itself, we find it hitched to everything else in the Universe.”

(John Muir. In Nature Writings. 1911)

ABSTRACT

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Smart products have the potential to change the lifestyle and working processes of their users. However, a perceived complexity of interaction with these high-tech artefacts may confound even the keen technology adopter. In response, human-value driven technology design approaches such worth-centred design, empathic and aesthetic design, and design for pleasure have emerged. Still, with increased availability of sensors and the wide spread of internet, the more technology-driven approach is prevailing. Further, Artificial Intelligence in form of complex reasoning and deep learning algorithms is making impressive comeback. In this sense, to balance and reflect technological complexity, User Psychology as a design discipline should be more taken in new products and services design. Humans use and create tools and artefacts that are meaningful to them. Motivation is a reason for people's actions, desires and needs. Hence, the motivation constructs and respective psychological theories such as Self-determination theory of motivation, Activity theory and related psychology of human awareness should be more taken into design of technology to maximize the benefits to the user and thus to make technology more acceptable.

This thesis explores the role of awareness as a psychological construct in determining human behaviour and consequently, its influence on how humans respond to the technology. The general design principles in form of design questions and vocabularies, which facilitate designer with systematic knowledge on awareness to be taken in technology design, are defined here. This thesis utilizes the Design science research paradigm in which questions relevant to human problems are answered via studying application domain, experimenting and the creation of innovative artefacts to come up with a solution to a defined problem. Further, the Design science research approach is combined with methods from Explanatory science, which are taken as a ground towards a theoretical synthesis of experimental findings. Conceptual analysis as a method of Foundational Analysis is used to investigate the content of experimental concepts through their recomposition and reconstruction to find more accurate cognitive science grounded understanding of respective concepts.

Keywords: HTI, Awareness, Design

TIIVISTELMÄ (ABSTRACT IN FINNISH)

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Tietoisuuden ymmärtäminen nykyaikaisessa tuote- ja palvelusuunnittelussa
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Älytuotteet voivat muuttaa käyttäjiensä elämäntapaa ja työprosessia. Näiden huipputeknologialaitteiden käytön monimutkaisuus voi kuitenkin hämmentää jopa teknologiasta kiinnostunutta käyttäjää. Vastauksena on syntynyt inhimillisiä arvoja ajavia teknologian suunnittelun lähestymistapoja, kuten arvokeskeistä, empaattista sekä esteettistä suunnittelua. Teknologiaan perustuva tuotesuunnittelun lähestymistapa on silti vallitseva johtuen antureiden saatavuudesta ja internetin laajalle leviämisestä. Lisäksi monimutkaiseen päättelyyn ja syväoppimisalgoritmeihin pohjautuva tekoäly on tekemässä vakuuttavaa paluuta. Käyttäjän psykologia on otettava paremmin huomioon uudessa tuote- ja palvelusuunnittelussa, jotta teknologista monimutkaisuutta saataisiin tasapainotettua. Ihmiset luovat ja käyttävät heille merkityksellisiä työkaluja ja laitteita. Motivaatio on syy ihmisten toimiin, toiveisiin ja tarpeisiin. Näin ollen motivaatiorakenteita ja vastaavia psykologisia teorioita, kuten motivaation itsemääräämisen teoria, toiminnan teoria ja niihin liittyvä ihmisen tietoisuuden psykologia, tulisi ottaa enemmän huomioon teknologian suunnittelussa, jotta käyttäjä hyötyisi maksimaalisesti, mikä tekisi teknologiasta hyväksyttävämpää.

Väitöskirjassa tutkitaan tietoisuuden roolia psykologisena rakenteena ihmisen käyttäytymisen määrittämisessä ja sen vaikutusta siihen, miten ihmiset reagoivat teknologiaan. Tutkimuksen tavoitteena on määritellä suunnittelukysymysten ja sanastojen avulla yleiset suunnitteluperiaatteet, jotka auttavat suunnittelijaa soveltamaan systemaattista tietämystä tietoisuudesta teknologian suunnittelussa. Väitöskirjassa hyödynnetään Design Science -tutkimusparadigmaa, jossa ihmisen ongelmiin liittyviin kysymyksiin vastataan tutkimalla sovellusaluetta, kokeilemalla ja luomalla innovatiivisia laitteita ratkaisun löytämiseksi määritellylle ongelmalle. Lisäksi Design science -tutkimuksen lähestymistapa yhdistetään selittävän tutkimuksen menetelmiin, jotka ovat perustana kokeellisten havaintojen teoreettiselle synteesille. Käsitteellistä analyysimenetelmää käytetään kokeellisten käsitteiden sisällön tutkimiseen. Näin löytyy tarkempaa kognitiotieteeseen perustuvaa kokeellisten käsitteiden ymmärtämistä.

Avainsanat: HTI, Tietoisuus, Tuotesuunnittelu

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I started my research on technology intensive product systems over 10 years ago in EU funded IST FP6 AMIGO project. This was my first project, where I had to learn a lot about IoT, smart home, semantics, user experience and so on. I'm very grateful to Tapio Frantti, who hired me second time, back to VTT – Technical Research Center of Finland, giving me this brilliant project and the opportunity to learn and to work on ambitious research topics, with brilliant researchers from Microsoft, Philips, France Telecom and Fraunhofer Institute, the division "AMBIENTE - Smart Environments of the Future", and dream-team colleagues, Ilkka Niskanen and Jarmo Kalaoja. The design science research artefacts presented in this thesis would have been difficult to develop without Ilkka's excellent software development skills and Jarmo's thinker attitude and passion for software architectural patterns. After AMIGO, there were EU FP7 Smart Products, FP7 COnCEPT and FP7 COnCORDE projects, where I learned new application domains and gained more technological expertise to deepen my research. I wish to thank VTT for making this possible.

At that time, around 2016, I felt that I am still missing an important bit to bring my research to some final point of internal satisfaction and practical implementation to be useful for other researchers too. I was lucky then, discovering great expert, Pertti Saariluoma, who took me as a student and led me in learning of those important missing bits of knowledge in cognitive science, user psychology and philosophy, which I needed to finalise my dissertation. Without Pertti's advises, seamless but at the same time, firm guidance and warm sense of humour this thesis could not have appeared.

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Espoo 2.7.2019
Julia Kantorovitch

FIGURE

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1 INTRODUCTION

1.1 Motivation

The ‘smartness’ and ‘intelligence’ as a concept has been investigated by several authors, in overlapping research initiatives and sub-fields from various perspectives. The origins of this research date back to 1960s when the field of Artificial Intelligence (AI) was officially born. The grand goal has been set at the Dartmouth summer workshop in 1956 with aim to develop ideas about thinking machines. Researchers were optimistic about that “machines will be capable, within twenty years, of doing any work a man can do” (Simon, 1965). After a period of temporary recession, in 1980s the AI research got an additional boost with the commercial success of expert systems. Only in the late 1990s AI began to penetrate to various applied domain specific research in logistics, medical diagnostics and so-called intelligent environments such as living space and work offices. The term ambient intelligence (AmIE) is created in late 1990s at Philips with attempt to “put people and their social situations at the center of the design considerations” (Aarts & Encarnação, 2006; Streitz, 2017). AmIE is built on the ideas of Ubiquitous Computing and Calm technology proposed earlier by Marke Weiser at Xerox PARC (Weiser, 1991). However, while Ubiquitous computing and follow-up research took technical approach towards the embedding of technology in everyday environment, AmIE in contrast tried to put more emphasis on user-oriented design and human perspectives in general.

Recently, with increased availability, robustness, and moderate cost of sensors and the wide spread of internet, the more technology-driven approach based on Internet of Things (IoT) is started to prevail again and undergoing. The idea here is that every physical object augmented with sensing technology is connected to the Internet and thus with every other object transmitting its monitored properties and state changes. An extension of IoT is Internet of Everything (IoE), a term introduced by Cisco, where processes, data and things as well as living organisms (people and animals) are connected to create “smart everything" - smart eco-systems of products and thus promising to be adaptive, responsive and smart.

At the same time, Artificial Intelligence is making impressive comeback showing an impact in a various areas such as speech analysis and autonomous driving. Some amazing advances, facilitated by image analysing software, have been demonstrated also in medical domains (Miotto, et al., 2017). The current boom of AI has been capitalised on recent advances of machine learning. So called deep learning algorithms, trained on the extremely large datasets are capable to exceed the performance capacity of human in visual tasks and in mastering the games. The most obvious results of power of AI are seen in a new consumer gadgets and experiences such as smart speakers (Alexa, Siri, etc.) and fingerprint and face recognition authentication software. Certainly there is evidence that AI can make our life easier in some aspects, however, before that some important human values-related questions should be addressed. For example, one challenge with deep learning models broadly discussed in the literature is that they are "black-box" approaches (Zhou & Chen, 2018). Deep learning algorithms are lacking explicit declaration knowledge and respectively the required underlining explanatory, which influence the trustworthiness of produced results. The constructs that support such features as transparency and interpretability are needed before technology can be widely adopted.

To balance and reflect technological trends and to meet the need to reconcile humans and technology, more human-oriented thinking technology design approaches have emerged. Among these there are value-driven approaches such as ethical design (Cairns & Thimbleby, 2003; Bynum & Rogerson, 2004), worth-centred development (Cockton 2004, 2005, 2006, 2008), empathic and aesthetic design (Koskinen, Mattenimäki, & Batterbee, 2003), and design for pleasure (Jordan, 2000; Bonapase, 2002). Value-driven design considers human values from different perspectives. Through incorporating human values to product design, it is possible to enhance the liking and wanting feelings towards the product and thus increase its personal value (Leikas, 2009; Niemelä, 2014). Empirical studies on flow experience associated with information technology use indicate, that flow experience may acquire frequently while performing a variety of tasks ranging from word processing to programming to visual design and information search on a desktop computer. Various studies on the subject suggest, that facilitating flow should be the goal of user interaction design (Pilke, 2004; Kiili et al, 2012).

It is widely acknowledged that pleasure in using a product or service requires more than functional usability but also the effects of emotional response (Jordan, 2000). Emotions determine the person's subjective meaning of situation, hence they are connected to the tendencies of human action (Frijada, 1986, 2007). Curiosity for example, encourages people approaching the object and feeling of insecure makes people hesitate. Functionality is a necessary condition for pleasurable interaction (Hancock, Pepe, & Murphy, 2005), however, non-functional requirements including pleasing experience are equally important (Olphert & Damodaran, 2004).

Personality has an important role in investigating HTI. A well-known example is the so-called Big-5 theory, which focuses on five basic personality traits: openness, conscientiousness, extraversion, agreeableness, and neuroticism to experience (e.g., McGrae & Costa, 1987; Wiggins, 1996). Human personality explains attitude related to how people consider technology. Attitude is linked to beliefs and emotions that govern the selection and processing of information. Information that is positive is accepted and information that is contradicted with prevailing attitude is often rejected (Aiken, 2002). Users' commitment to a product may depend on different aspects of personality (Kim, Han, & Park, 2001). Various mental contents, motives and values are reflected by an individual's personality (Saariluoma, Cañas, & Leikas, 2016).

Motivation is recognised as an important factor in technology design (Torning & Oinas-Kukkonen, 2009; Seaborn & Fels, 2015). Motivation is relevant in explaining why people use technologies as well as to what extent different designs help motivate individuals to use particular product. Motivation is related to emotion and affective design because emotions are in part the response on the progress and state of the mind (Saariluoma & Jokinen, 2014). Through people may use technology, it not necessary means that they like or want to use it. Consequently, when designing new products and services, the aspects concerned personal emotions, motives and personality are important in understanding why people adopt certain technology (Saariluoma, Cañas, & Leikas, 2016). Examining motives provides answers why people perform different tasks and how energetic they are to pursuit their goals (Franken, 2002).

We observe that humans are situation aware. We use our built-in perceptual and augmented senses to interact and to control our surrounding world. We can quickly look around and identify whatever we are interested in of what we see. We can also recognise known situations and learn about new situations. How we do this and why? What motivates us?

Motivation is a reason for people's actions, desires and needs. Motivation can come from others and external events and also from within the individual (Deci & Ryan, 2000). Motivation is central in the design and creation of tools. Technology is something created by human. Humans use and create tools and artefacts that are meaningful to them (Hancock, 2009). For example, according to Activity theorists, "all human experience is shaped by the tools and sign systems we use. Mediators connect us organically and intimately to the world" (Nardi, 1996). Tool can be any artefact used in the transformation process, including both material tools, software tools and tools for thinking. Hence, the motivation constructs and related psychological theories such as social, cognitive and psychology of human awareness should be more widely taken into design of technological tools and artefacts to maximise the benefits to the user and thus to make technology more acceptable.

The work of (Saariluoma, 2004, 2009; Saariluoma & Oulasvirta, 2010) has emphasised the important role of *User psychology*, as a design discipline. User psychology endeavours to bring the central psychological conformities and constructions as part of the design process and as a basis for technology design.

To date, however, there are not enough of broadly applicable technology design principles, which translate the human psychological inner needs and related constructs as well as the aspects of human motivation into technology design (Szalma, 2014). In this sense *Design thinking* based approaches should be more taken in new products and services design (Maciver, Malins & Kantorovitch, 2016). Design thinking emphasizes the value of interdisciplinarity in all stages of design process, where key concepts and attributes of design thinking can be identified and brought in design across different domains combining theoretical knowledge from design, arts, science and also market research (Cross, 2001, 2011).

1.2 Objectives

There are several theoretical perspectives that have contributed to our understanding of motivational factors and the psychology of awareness that influence human behaviour and may help to design the technology.

The user psychology is helpful to valorise the role of human motivation in the technology acceptance. Examining users' goals and motives provides the knowledge why people do what they do. Motivation has biological, cognitive, emotional, and social elements (Saariluoma, Cañas, & Leikas, 2016). Understanding motivation is an important in analysing why a defined goal is important for a certain group or individual.

Existing theories of motivation such as goal-setting theory (Locke & Latham, 1990) and expectancy theory (Vroom, 1964) define motivation for the particular behaviour in forms of the character of goals and expectations of the rewards. Since their establishment, in particular goal-setting theory has been the most researched and utilized in work motivation in the field of industrial and organizational psychology.

In contrast the theories, which are represented by Maslow's hierarchy of needs (Maslow, 1948) and Self-determination theory - SDT (Ryan & Deci, 2000), approach to the motivation and goals settings from the "needs" point of view to explain why particular goals are selected. The structure of needs and motivation has been studied by applying the concept of the depletion–repletion cycle (Toates, 1986). Here, human physiological needs activate people towards certain goals. The state before satisfaction is called *desire*, because it has a goal but not always the means to reach it. When an individual finds a way to satisfy a need, the need state is deactivated or depleted (Saariluoma, Cañas, & Leikas, 2016). As discussed earlier, *emotions* have an important role in understanding motivation as they inform people about needs. Pleasure as an emotional state is seen as a motivational goal (Jordan, 2000; Hassenzahl, 2011).

Cognitive aspects of motivation can be considered in the relation that technology can offer in improving individual's tasks' outcome, expertise, abilities and skills. Such cognitive phenomena as *intention*, *learning*, *perceived self-efficacy*, and *usefulness* are factors that explain the cognitive aspects of motivation when using technologies (Yi & Hwang, 2003). People identify the emotionally important features in the environment through an *assessment process*. The emotions activated by cognitive mind (e.g., fear or joy and curiosity) create motives for action (Lazarus & Lazarus, 1994; Power & Dalgleish, 1997).

Personality is an important concept in analysing how people as a whole accept and use technologies. An individual's personality reflects a wide range of possible *mental contents* including attitude, individuals invoke in different situations. Attitudes are acquired tendencies to apperceive information in a certain way (Saariluoma, Cañas, & Leikas, 2016). Numerous motives in human life are also social by nature (Dunning, 2004; Ryan & Deci, 2000). The interaction of cognitions, emotions and motives integrated by the personality research is based on the cognitive, dynamic and motivational *schemas* individual may have to form an action. The interconnectedness of needs, emotions and motives play a multifaceted role in actions (Deci, Koestner, & Ryan, 1999; Ryan & Deci, 2000; Franken, 2002)

Motivation is a combination of two types of factors influencing human actions: *extrinsic* and *intrinsic* motives (Deci, Koestner, & Ryan, 1999). Extrinsic motives involve different external factors that influence human motivation. The motivation to use technologies can be extrinsic, so that people use certain tools because they are expected to use them to, for example at work. Intrinsic motives are internal, and people set these motives for themselves. For example, people may use technology to learn things more effectively or to express themselves. Intrinsic motives are more dominant than extrinsic motives. Understanding intrinsic motivation is important in designing any product (Saariluoma, Cañas, & Leikas, 2016).

According Maslow's hierarchy of needs people are motivated by satisfying lower-level needs such as food, water, and security, before they can move on to being motivated by higher-level needs including self-actualization (Maslow, 1948). Self-determination theory progressed further towards the understanding the nature of motivation and human needs and instead points to three universal psychological needs represented by perceived feeling of autonomy, relatedness, and competence (Ryan & Deci, 2000). In other words, self-determination refers to how competence, relatedness, and autonomy form the core of intrinsic motivation.

These three psychological needs motivate the *self* towards the specific behaviour and attitude. When these needs are satisfied, there are positive consequences leading people to be motivated, productive and happy. Moreover, the psychology of awareness, which is in particular relevant to the subject of this dissertation, is postulated by the SDT theory. According Self-determination theory, among the functions essential for autonomy is awareness (Ryan & Deci, 2000). The awareness is conceptualised as "clear perception and insightful understanding of events" or "a relaxed attention and interest in what is occurring" (Deci & Ryan, 1985; Ryan & Deci, 2008). Awareness is foundational to autonomy as a tool towards supplying its information basis. Awareness may support cognitive, social and personality-related dimensions of motivation.

Above described concepts and constructs are important and influential on human behaviour. Consequently, they must also have their role in how humans respond to the technology. Helping people to experience certain awareness while interacting with technology through an employing SDT-aware design can improve the user experience and thus the acceptance of technology-based systems in various modern technology-intensive products and services. In other words, *the hypothesis explored by this dissertation* is that by investing and creating of various artefacts, which aim at supporting/enabling awareness while using technology towards satisfying inner human psychological needs, the challenges related to the acceptance and take-off of technology can be better managed. This dissertation takes the viewpoint of the end-user, however, aims at supporting service developer in mastering of Awareness aspects in modern systems of products and services.

Hence, the research questions this thesis aims to address are:

RQ1 What Awareness means in various real-life contexts (end-user point of view)?

RQ2 Which elements constitute Awareness (end-user point of view)?

RQ3 How to design Awareness taking into account well established psychological constructs of human universal psychological needs and motivation - the Awareness requirements must be taken into account in early phases of the service/product engineering (designer point of view)?

The ultimate goal of this thesis is to provide general design principles in form of design questions and common vocabularies (framework), which facilitate designer with systematic knowledge on awareness to be taken in technology design.

1.3 Scope

The scope of this study is an open modern smart product systems, however, not time critical decision support systems, and not the systems that operator need not to be motivated to use technology such as, for example, air traffic control, large complex manufacturing systems, some medical and tactical and strategic systems. Indeed awareness is related to decision making and problems solving, however, decision support systems are not part of this research as such.

'Situation Awareness' for time-critical systems and its relation to human factor in decision-making is well studied by Endsley (Endsley, 1995a; Endsley, & Garland, 2000; Endsley, 2006; Endsley, Bolte, & Jones, 2011). There is implicit assumption that operator is already motivated in use of technology either motivation is organizational concern.

This research on awareness instead aims at addressing the *motivation* to use the technology and the *openness* and *simplicity* in the technology design.

This is in particular important in the context of everyday use of technology at home and at work.

Emerging technologies open up new visions and business potential for systems design and development in the areas of human life. If we take a close look at today's technical products, starting from small consumer goods all the way up to cars and airplanes, it is possible to clearly identify certain trends:

- Increased complexity of technical products;
- Emerging diversity within production lines;
- Growing amount and diversity of product-related data, information and content;
- Need for interoperability in open environments.

It is very easy to forget about the user in enormous technical complexity the designer and service developer have to deal with. Mastering of "openness" but also "simplicity" will determine the success of the digital products and services success in the future. Openness is related to the participation of various stakeholders in the creation of products and services, hereby allowing the complementary bottom-up approach in smart systems development. Users demand simplicity. Simplicity is related to usability and there is a trend in industry to conflate these terms as much as possible. Sound simplicity will increase user acceptance of technology, which is crucial for products take-off in many contexts. Some recent examples have proven that:

- With the rise of popularity of Apple personal computing devices, usability has been taken to the level of when usability has started to be prevalent the functional features of technological products (ref. iPhone 1st generation 2007);
- Dashboard design in today's automobiles is driven very much by aesthetics than by functional features. In spite that it is currently trendy to give the driver a lots of information, most of it has little impact on decision making, it is rather to allow driver feels in control of his/her powerful machine;
- Consumer driving technology development is seen also in the manufacturing domain. With the rise of smart home devices like Amazon Echo and Google Home, consumers' trends and behavioural data can be informed to down to supply chain and related manufacturing processes. Accordingly it will be seen in the future the rise of smaller production sites being established much closer to the consumers themselves, for example within densely populated cities and living communities.

1.4 Research approach

This thesis utilizes the *Design science (DS) research paradigm*, where the novel scientific knowledge are acquired by the setting of questions relevant to a particular problem in application domain and by answering them via experimenting and the creation of innovative artefacts (Hevner, March & Park, 2004; Hevner, 2007; Iivari, 2007; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). Design science research is motivated by the desire to improve the environment by the introduction of new and innovative artefacts and the processes for building these artefacts (Simon 1969). Sometimes design science research is also about potentiality i.e. the identification of new opportunities to improve practice before any problem is recognized (Iivari, 2007). Design science is primarily a problem-solving paradigm that calls for improving the effectiveness and utility of an artefact in the context of solving real-world problems. Artefacts may be models, methods, constructs and instantiations (Hevner, 2004). Consequently, a DS artefact can be any design object in which research contribution is embedded in the design (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). In the field of information systems, DS research combines a focus on information technology artefacts with a high priority on relevance in the application domain (von Alan et al., 2004; Iivari, 2007). The development of artefact in DS research is a creative search process which is based on an existing theories and knowledge. The DS research presumes a rigor in the development and the evaluation of research artefacts. Depending on the nature of the problem evaluation may include quantitative and qualitative measures, results of satisfaction surveys, client feedback or simulations (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007).

The HTI design is a complex task due to the complexity and multifaceted nature of human knowledge to be taken into the product design to support individual with his/her tasks to carry out in context. Design Science has its roots in Design thinking, which is oriented towards practical problems in human life (Simon, 1969). In this way, *Design science is a suitable approach here to start*, also because it emphases the importance of understanding an application context and it is consistent with normal human problem solving such as setting goals and searching for intermediate solutions (i.e. artefacts) to achieve them (Simon, 1969). The DS research here has been also influenced by the ideas and methods used in a *reverse engineering* (Chikofsky & Cross, 1990), where product is inspected by designers by deconstructing it into pieces to understand its architecture, logic or design to find a way to improve it. In our case, the focus of analysis in various application cases has been put on how people (householders, assembly line workers, incident rescuers, product designers) use products and how redesign and introducing an additional innovative artefacts could help the product/service better serve the uses' purposes.

Further, the DS research approach is combined with methods from *Explanatory science* research (Saariluoma & Oulasvirta, 2010), which are taken as a ground towards a theoretical synthesis of experimental findings. Conceptual analysis as a method of *Foundational Analysis* (Saariluoma, 1997) is used to investigate the content of experimental concepts through their recomposition and reconstruction to find more accurate psychology- and cognitive science-grounded understanding of respective concepts. The ultimate goal of reconstructing an area around an explanatory framework is systemization of psychological knowledge in the respective areas (Saariluoma & Oulasvirta, 2010).

Consequently, the research questions are approached by bottom-up approach, from application domain specific studies to the generalization and theoretical scientific model, by examining various application domains such as future smart home and aircraft assembly line, emergency and disaster events and finally collaborative product conceptualization context and related supporting technology. The research is carried out by analysing the respective domains from research questions point of view, by deriving the requirements, by prototyping the required functionalities and knowledge models and finally by carefully evaluating the proposed methodology in each domain and deriving the lessons learnt towards the theoretical implications to be resulted from this dissertation as visualised in Figure 1.

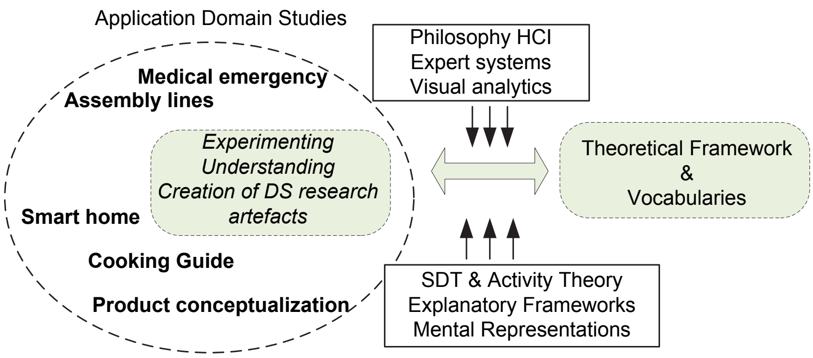

FIGURE 1 Research approach

The *scientific papers* are considered as the most important milestones of the study. They introduce case studies, key findings and innovations and finally provides with input towards the theoretical summering of the proposed extensions and awareness model. There are six main publications (and several supplementary publications closely related to the contents of this thesis) that are enclosed in this thesis.

The research carried out and reported in this dissertation can be divided into several research ensembles as follows:

1. State of the Art Analysis
2. Domain specific studies
    a. Smart home
    b. Future production line environment, a case study in aircraft assembly

   c. Medical emergency response
   d. Collaborative product conceptualization
3. Theoretical summary of the proposed framework including the input from cognitive science and user psychology

The analysis of *the State of the Art* in the domain, which aims at finding the scientific theories and/or engineering methods that provide foundations for the research work, is the essential part of this study in its various stages. The objective of the State of the Art analysis is to capture the concise state of the filed (scientific theories, techniques, trends and technology) in the domain of the subject of dissertation. In some application contexts the assessment of existing technology has be carried out. The relevant findings resulted from this stage are taken as an input to the study of application domain-specific cases. The State of the Art analysis is carried out during various stages of research as a literature survey.

The domain specific studies aim at analysing number of application cases from awareness point of view towards understanding of the domain, identification of the requirements to awareness, prototyping and finally the evaluation of the proposed artefacts. Depends on the application case, the requirements are collected through a multi-faceted approach, which has included literature review as well as thinking aloud, interviews and workshops with end-users and domain experts (Ericsson & Simon, 1984). The details of methodology used are reported in the related publication articles. The important part of this work is the testing (evaluation, validation and assessment) of proposed artefact. The testing of software components is an investigation performed to provide stakeholders with information about the quality of the product or service under test. Such criteria as interoperability, performance, security, efficiency, usability, accuracy can be assessed to determine the quality of software. The particular criterion chosen depends on the nature of software components and the context of its usage (Nielsen, 1994; Davis, 1989; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). Due to the nature of research topic of this dissertation, the aspects related to usability of created artefacts are the most important characteristics being assessed.

The overall analysis and synthesising of domain specific results towards a *Theoretical Framework* are carried out in the third final stage of the research. Here the previous studies on awareness reported in a course of HCI research as well as psychological theories of motivation and Activity theory and existing explanatory frameworks (Saariluoma & Oulasvirta, 2010) are taken as a ground for the theoretical synthesis towards a new knowledge to support human-design-thinking approaches. Several major complementing conceptions of the user in contemporary research such as cognitive schools of HCI grounded on analytical model of human mind, activity theorists in HCI and phenomenology have been examined for proposing a synthesis.

The notion of *Ontology* is extensively used in the text of this thesis. The ontology is a broad concept and may impose different meaning depends on the context of use, field or the background of applier/responder. In philosophy for instance, the word ontology is used to refer to general philosophical investigation of existence, or being. In design science, the wording 'Ontology of Designing' is often used to represent a relevant knowledge about design methods, procedures and design questions (Gero, 1990; Saariluoma, Cañas, & Leikas, 2016). In information science, ontology is a way to define the concepts (vocabularies), properties, and relations between the concepts to describe a particular domain (Chandrasekaran, Josephson, & Bejamins, 1999). The latter definition is used here to substantiate awareness and relevant theoretical concepts to facilitate designer with systematic knowledge and vocabularies to be taken in product design hereby *mediating psychological knowledge to technical designers.* Interpretations of certain terminology vary according to the background and discipline of experts. Psychologists and other creative-dominant specialists are seldom specialised in information systems and designers are normally not involved in modern psychology, sociology, cognitive and market sciences (Saariluoma, 2009; Maciver, Malins, Kantorovitch, & Liapis, 2016). Ontology based approaches is one way to support communication and effective knowledge transfer in multidisciplinary groups (Chandrasekaran, Josephson, & Bejamins, 1999; Leppänen, 2005; Baxter, Gao, & Case, 2008; Liu & Lim, 2011; Hao, Guoxin, & Gong, 2013). Further, ontology term is used here to define a tool to support creative design thoughts by facilitating designers with question, fundamental concepts and their contents in the domain of user psychology and awareness in particular (Saariluoma, Cañas, & Leikas, 2016).

1.4.1 The results

The result of this research is a compilation dissertation containing introduction and collection of scientific publications. This research ultimately aims at stressing the importance of the "Awareness" as a psychological construct for design of the modern technology based products and services.

Further, the important objective of this research is to develop new knowledge and theoretical framework, in form of design questions and vocabularies, which will complement and extend the earlier research on human awareness and that the professionals of application filed in question can use to design solutions for their field problems. By answering the defined research questions this study, aims at bringing new perspective on what kind of requirements to knowledge, their construction and dimensions are needed to support the incorporation the awareness aspects into the design of future technology-intensive products and services in consumer and professional context towards their better acceptance.

Numerous application use cases resulted from domain studies are defined to support our understanding and the definition of the proposed awareness model. Derived use cases can be also used as instantiation examples for some application fields. Besides, of evaluated quality of proposed concepts and tools, the performed evaluations provide information about their applicability in real-life usage.

1.4.2 Author's contribution

The studies reported in this thesis have been performed in a joint international projects in the collaboration with various researchers from VTT - The Technical Research Centre of Finland and abroad. The author's contribution and the roles of other contributors to this research are summarised in the following.

In Paper I, *"Interactive home supervision application -think visually"*, the author of this thesis is the concept designer and a main writer of the publication. In addition, she has participated in evaluating the developed technology with the users during "Hyvä ikä" exhibition. Mr. Ilkka Niskanen has contributed with the development of the application.

In Paper II, *"Towards the user confidence in sensor-rich interactive application scenarios"*, the author of this thesis has contributed with the design of explanation interfaces for the cooking guide application and with writing of the publication. Mr. Ilkka Niskanen has been working on the implementation of the visualization aspect of explanation interfaces.

In Paper III, *"Monitoring and Visualization Approach for Collaboration Production Line Environments: A Case Study in Aircraft Assembly"*, author of this thesis has contributed with the design of SP Monitor software, its evaluation and writing of publication, in particular analysing the technological state of the art in the domain of awareness applied to industrial environments. Mr. Ilkka Niskanen has contributed with the design and implementation of SP Monitor and writing the publication. Mr. Jerom Golenzer has provided the research team with the domain knowledge in EADS context.

In Paper IV, *"Designing Situation Awareness: Addressing the needs of Medical Emergency Response"*, the author of this thesis is a main writer of the publication. She has designed the awareness model addressing the case of medical emergency response. Mr. Ilkka Niskanen and Mr. Jarmo Kalaoja have been helping with the design of EDXL-based ontologies and with providing linked data expertise respectively. Dr. Toni Staykova (Cambridge University Hospital) has contributed with domain-specific expert knowledge on medical emergency response and user requirements acquisition.

In Paper V, *"Supporting the initial stages of the product design process: Towards knowledge awareness and inspiration"*, author of this thesis is a main writer of the publication. She is a main contributor to the concept innovation, studies of needs and requirements to technology, architecture and prototype design, and evaluation. Mr. Ilkka Niskanen and Mr. Antti Nummiaho were contributing with software development and prototyping. Other co-authors from design companies have been helping with domain expertise in the area of product design.

The Paper VI, *"On Importance of Awareness in Modern Smart Product Design"*, which describes the theoretical framework to support the designers in taking awareness in product design, is a compete effort of the thesis writer.

2 AWARENESS – EXISTING RESEARCH

The concept of "Awareness" is complex construction. It postulates the way on how humans relate themselves with respect to surrounding environment, artefacts, people and things which maybe abstracted as a situations. Both 'awareness' and 'situation' found their theoretical ground in philosophy, psychology and cognitive science. Awareness and somehow related concepts of situation- and context-awareness have been continuously studied also in computer science as a part of HCI research in complementary forms of Human Factor research, Computer-Supported Cooperative Work, Context-aware computing and so on as presented in Figure 2. In the following, a major research effort on awareness and situation is outlined to highlight valuable insights that have guided and inspired this research.

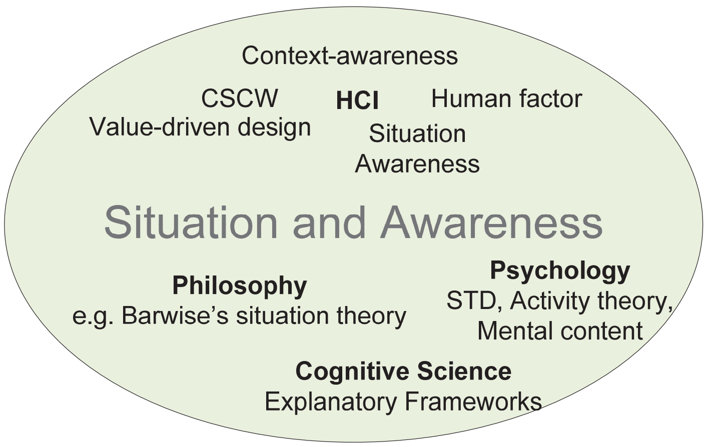

FIGURE 2 Situation and Awareness and related research fields

2.1 Awareness from Philosophy to Computer Science

The earliest formal notion of situation and its relation to awareness in form of information is introduced in Barwise studies (Barwise, 1989). In the beginning, it aimed at the modelling of information flow, in the context of language and communication, ''people use language in limited parts of the world to talk about (i.e. exchange information about) other limited parts of the world". Those limited parts of the world are called situations. "Events and episodes are situations in time, scenes are visually perceived situations, changes are sequences of situations, and facts are situations enriched (or polluted) by language" (Barwise & Perry, 1983).

Situation is, however, generalised as corresponding to the limited parts of reality we perceive, reason about, and live in. In situation semantics, basic properties, relations, events and even situations are made concrete as objects to be reasoned about. Once a situation is made into a concrete object, various properties can be associated with the situation. With limited information, a situation can provide answers to some but not all questions about the world.

Technically, situation theory is a mathematical theory of meaning (Devlin, 1991). According to the theory, individuals, properties, relations, spatio-temporal locations, and situations are basic constructs of situation theory. The world is viewed as a collection of objects, sets of objects, properties, and relations. Objects are the parts of individuals. Words are seen also as objects. All individuals, including spatio-temporal locations, have properties (like being frag- or red) and stand in relations to one another (like being under). Information flow is made possible by a network of abstract 'links' (Tin & Akman, 1994).

One of the distinguishing characteristics of situation theory is that information content is situation-dependent. Language is an integral part of our everyday experience. The activities such as talking, listening, reading, and writing are situated, - they occur in situations and they are about situations. What is common to these situated activities is that they convey information which is important for us human beings (Tin & Akman, 1994).

Situation theory aims at supporting various features such as self-reference, assertion of situations, access to the relationship between situations, etc., that can be used in Artificial Intelligence and Natural Language Processing applications. In practice, these features may establish rich knowledge representation formalism for a computational framework based on situation theory.

A known challenge in the design of knowledge representation formalism is the finding of trade-off between expressivity and practicality (Davis, Shrobe, & Szolovits, 1993). The effective knowledge representation formalism to define general propositions about the world in terms of expressiveness and compactness is First Order Logic (FOL). However, it has drawbacks related to its complexity and practicality and consequently, difficulty of implementation for software developers. Thus in practice, the subsets of FOL are used in many cases, such as in rule-based expert systems, for example. Furthermore, semantic web technologies enabled by knowledge representation, reasoning and XML based mark-up languages such as Resource Description Framework (RDF) and Web Ontology Language (OWL) are defined to represent knowledge concepts. Semantic technologies have been extensively used in this research and development to describe respective application domains of designed products. A semantic approach towards the use of in particular situation theory is introduced by Kokar in (Kokar et al., 2009). This approach aims to capture situation as a theoretical construct within Web Ontology Language and thus to bring situation theory in practical use to assess various real-word situations.

The semantic situation theory is interesting and inspiring approach to model various real-world situations. While it was not used directly in our following experimental studies, it served as an inspirational work to approach to the domain-specific semantic knowledge modelling towards the awareness design, as discussed in Chapter 3.

2.2 Awareness in Psychology

The psychology is the study of user behaviour and mind, about how mind works and how it affects behaviour. Awareness is a state of mind hence there must be a suitable psychological concepts to explicate it better. Mental contents, the content of the information in the human mind that people use to guide their actions must be examined, when investigating technology interaction process in which consciousness and thinking play an essential role (Simon, 1955; Newell & Simon, 1972; Saariluoma, 1990, 1997, 2003).

There are different branches of psychology such as cognitive-, developmental-, and neuropsychology, as well as consumer and social psychology, that serve different purpose and help to understand human mind. For example, the developmental psychology studies psychological changes (cognitive, motivational, social, etc.) that a person experiences over the life span, often referred to as human development (Hogan 2000). Instead, cognitive psychology investigates mental processes. It provides concept to understand such processes as thinking, perceiving, remembering, and learning (Neisser, 1967). Social psychology aims at understanding how social interaction may affect human behaviour. It offers some concepts to explain how "feelings, behaviour, and thoughts are influenced by the actual or imagined presence of other people or historical context" (Allport, 1985).

In historical context, psychology was in place already in ancient Greece, Egypt, India, Persia, and China. In 387 BCE, Plato suggested that the brain is where mental processes take place, and according Aristotle it is the heart. The concepts such as mental representation, mental content and information comprehension as a results of *apperception* process which unifies external information with existing memory representations (mental contents), were theoretically developed already in 17th century by Leibniz (1704/1981) and Kant

(1781/1976). Psychology was a branch of philosophy until the 1870s. The first laboratory that carried out psychological research as independent research field has been set up then at Leipzig University by Wilhelm Wundt. Soon after the development of experimental psychology, various kinds of applied psychology appeared. The psychoanalysis has been developed by Sigmund Freud. In 1913 a new movement, behaviourism has been founded by an American psychologist, John B. Watson. Behaviour is seen as the result of how we respond to the environment, but not the result of internal mental processes. Unhappy with behaviourist approach, cognitive psychology became important in the mid-1950s. Interest in mental processes and their influence on human behaviour have been gradually returned through the work of Tolman on so-called cognitive maps (Tolman, 1948) and the work of Piaget on schema (Piaget, 1926) and cognitive model of human cognition (Piaget, 1952). The concept has further expanded in psychology and education through the work of the psychologist Frederic Bartlett on schema theory and by Ulric Neisser with publishing his book on Cognitive Psychology 1967 (Neisser, 1967). In addition, Neisser has further explained the schema and its relation to the visual perception of humans.

Schema is an important construct which helps to understand and explore the concept of awareness. According Piaget, schemas and schemes are the basic building blocks of intelligent behaviour and a way to organising knowledge (objects, actions, and abstract concepts) and thus enable us to form a mental representation of the world. We use these mental representations to understand and respond to various objects and situations. For example, we may have a schema in form of the script about buying a meal in a restaurant, which includes looking at the menu, asking food, eating and paying the bill. This schema/script can be retrieved when we are in a restaurant and applied to the context of situation.

Jean Piaget (Piaget, 1926, 1952; Wadsworth, 2004) viewed intellectual growth of a child as a process of adaptation (adjustment) to the world. This happens through assimilation (using existing schema to deal with new situation), accommodation (adjusting existing schema with new situation) and equilibration. Equilibrium occurs when a child's schemas can deal with most new information through assimilation. However, an unpleasant state of occurs when new information cannot be fitted into existing schemas. The need to deal with new information to restore balance is the force, which drives the learning process which keep us from frustration (Sivakumar & Thirumoorthy, 2018). Piaget considered schemes to be operative and in a sense content free and schemas to be figurative and configurational and which are more concrete (Piaget, 1952), such as for example, humans have a schema i.e. concrete representation for "grandmother" or "apple". Together scheme and schema form a structure, which drives the development and making sense of the world. Piaget is considered as a founder of constructivism, which is a philosophical viewpoint about the nature of knowledge, representing an ontological angle (Piaget, 1971). Finding the analogy from the meaning of ontology in information science, schema in cognitive science can be understand as an ‘instantiation’ of the ‘conceptual’ representation of the world.

Furthermore, according Neisser (Neisser, 1976), “the schema is not only the plan but also the executor of the plan. It is a pattern of action as well as a pattern for action.” According to Neisser’s perception-action cycle model (see Figure 3), visual perception is a continuous activity of looking at things which involves the anticipation of information (Neisser, 1978). This process depends on certain internal structures, or so called 'schemata," that function as anticipations and as plans. At any moment, the human anticipates that a certain sort of information will become available, and he/she gets ready to accept it.

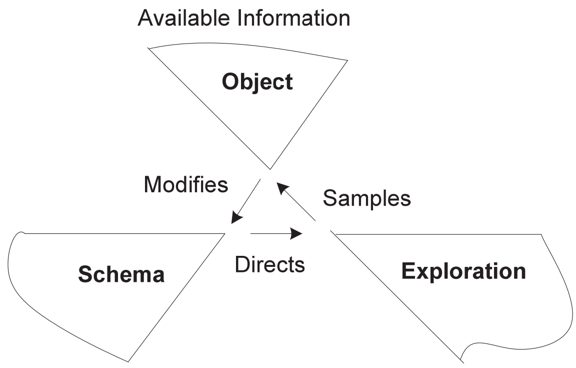

FIGURE 3 The Neisser’s perception-action cycle

The human schemata are a complex construct. It accepts information from many sources simultaneously and directs explorations of many kinds (Neisser, 1978). Accordingly, the perception process is also based on multimodal anticipations. When these anticipations are not fulfilled, the result can be disturbing. The anticipatory schemas play an important role in preparing the mind for perception of sensory events from ‘environment’, attention to them and their categorization. *Awareness* can be explicated as a mental state achieved through the process of equilibration which is created and sustained through this perception-action cycle as well as the adaptation cycle of assimilation, accommodation and anticipation.

Schemas are formed and changed throughout life. Object schemas are one type of schema. For example, most people have a schema for a car or different types of cars for example sport car. Other schemas people may have are for example social schemas, person schemas or self-schema *Person schemas* are related to specific person, which may include information about behaviours or personality or appearance. *Social schemas* contain knowledge about behaviours of people in certain social contexts. *Self-schemas* contain the knowledge about ourselves, - now and as visualised in the future based on the past experiences. *Situation schemas* may contain a course of actions people usually perform in a particular situation like in restaurant discussed earlier. Expert knowledge for example is organised in deeply multi-integrated schemas (Simon, 1969).

The term belief is used to represent a variety of schema-related constructs such as assumptions, expectancies, fears, rules, and evaluations influencing memories, abilities and associations (Beck, 1967, 1996, Beck & Haigh, 2014). The mental content of beliefs plays a crucial role in applying meaning to experiences.

Naturally, schemas as mental representations and their mental contents play a role on how we accept information, learn new things and make certain decisions and choices (Newell & Simon, 1972; Saariluoma, 1990, 1997). Maintaining belief or a certain schema about certain thing or situation may cause people to interpret situations incorrectly or react on certain artefact (e.g., technology) in a certain way. Mental contents are important in the user psychology of thinking. Analysing the information content of human mental representations and activating anticipatory schemas can help to predict human behaviour and design the technology accordingly (Saariluoma, 1990, 2001, 2003). Awareness is also related to the *"meaning-making"*. In psychology, this term means the process of how people construct, understand, or make sense of life events, relationships, and the self (Kegan, 1980, 1982; Ignelzi, 2000)

There are also psychological theories, which span over various psychological fields. For instance, Self-determination theory (SDT) studies human motivation and personality that concerns people's inherent psychological needs. It explains the motivation behind choices people make and it is used by other subfields of psychology such as developmental, social and consumer psychology to explain relevant phenomena of concern (Deci & Ryan, 2000). Other example is Activity theory (AT). Theoretically, the issues addressed by activity theory are close to the subject of philosophical and socio-cultural psychology (Holzman, 2006), which is related to object-oriented, collective and culturally mediated human activity. The activity is motivated in AT through the external and internal processes such as tensions and contradictions within the elements of the system. AT has its roots in the Soviet Union. Later AT has found its support and application in the Scandinavian countries (Engeström, 1999).

Nowadays, psychologists and social and computer scientists study all these theories and try to leverage what appears to be best from each approach to explain a particular situation. This approach is also followed here.

In fact, it can be safely said that the psychology of awareness is postulated by the Self-determination theory. According SDT theory there are *three innate psychological needs, perceived competence, autonomy and relatedness,* that if satisfied, lead to metal wellbeing and self-motivation. It was also shown that variations in the fulfilment of each of three needs independently predicted variability in daily wellbeing such as mood, vitality, physical symptoms and self-esteem (Ryan & Deci, 2000).

These needs are defined as required 'inputs' that contribute positively to human thriving (Ryan, 1995). Autonomy involves the feeling of internal comfort with own behaviour and self, availability of choices rather than feeling controlled; competence involves feeling efficient, effective, and even masterful in own behaviour, rather than incompetent and ineffective; and relatedness involves feeling meaningfully connected to others (Deci & Ryan, 2000). The origin of autonomy as self-determination and self-mastery can be found in ancient Greek philosophy. Already Plato and Aristotle associated the ideal for humanity with self-sufficiency and a lack of dependency on others.

For example in game-learning context, studies by (Sheldon & Filak, 2008) have demonstrated that anything that makes players feel less autonomous, competent, or related may also undermine their intrinsic motivation for the activity, as well as potentially undermining their objective performance at that activity. For example, when both competence and autonomy were threatened, participants were especially unwilling to recommend the game to others.

According Self-determination theory, among the functions essential for autonomy is *awareness* (Ryan & Deci, 2000). High-quality awareness puts people in better touch with their needs, feelings, interests and values as well as external conditions. Awareness is foundational to autonomy, supplying its information basis. Awareness allows people to be more in touch with their emotions and experience. It therefore enhances autonomy by fostering fuller access to varied parts of personality (Deci et al., 2015). In this recent study the SDT research is turned into two forms of awareness, mindfulness and interest taking. Whereas mindfulness involves being open and receptive to whatever is occurring in the present, interest taking represents a form of inquiry that can lead to insight.

In conclusion, awareness is an important construct because it helps people to satisfy their psychological needs for competence, autonomy and relatedness and it is considered as one of the regulatory process to support various types of motivation. The inner psychological needs can serve as requirements to be satisfied, and as motives to direct behaviour, thus, technology that supports need satisfaction will facilitate motivation for using the technology.

2.3 Awareness in HCI research

The field of Human Computer Interaction (HCI) research aims at the understanding of user and at the design the technology that supports various anticipated and derived use cases and situations of use the technology. Hence perceived awareness is related to this filed. The field of HCI is a massive and continuously evolving research area as visualised in Figure 4, and the objective here is to look on it from the prism of “Awareness” research.

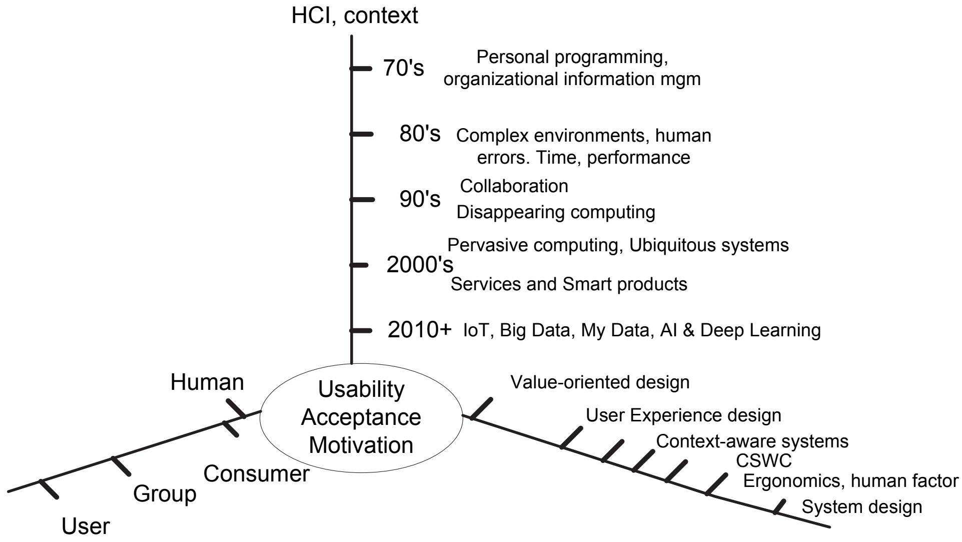

FIGURE 4 Research paths, trends and contexts in HCI research

2.3.1 The beginning

Until the late 1970s, the HCI research was conducted at large by technology developers and professional programmers (Carroll, 2013). The focus has been mainly put on the system functional design. This changed, however, with the emergence of personal computing, which with introduction of personal productivity-enhancing applications and interactive games, made everyone a potential computer user. The challenges with personal computing humans experienced, while working with command line and text editors, called for more user-oriented engineering approaches and related theories in ergonomics, cognitive psychology, artificial intelligence, linguistics and philosophy to address the needs of HCI.

2.3.2 Technology acceptance and usability measuring

In the 1980's, user perspective gained ground in the HCI research by involving behavioural sciences in the field. Researchers started to focus on what user needs including the usability of devices and non-functional requirements to user interfaces and acceptance of information systems. Consequently, the Technology acceptance model (TAM) has been introduced around this time (Davis, 1989), as well as the metrics and methods towards the measurement of usability have been proposed (Nielsen, 1993).

The TAM model suggested that when the user is presented with new technology, two main factors – 'Perceived usefulness' and 'Perceived ease-of-use', influence the humans' decision about the usage of technology, especially speaking of information technology in organizational context, which was a subject of the extensive research then. TAM is based on a Theory of Reasoned Action (TRA) from social psychology, which is concerned with attitude measures (Ajzen & Fishbein, 1980). According to TRA theory, a person's behaviour is determined by his or her behaviour intention (BI) to perform certain action and BI is jointly determined by the persons' attitude (A) and subjective norm (SN) concerning the behaviour in question (BI = A + SN). Subjective norm may include number of weighted variables such as user characteristics (cognitive style, personal), task characteristics, political influence, organizational structures, etc. TRA made at attempt to link the internal psychological variables to external variables influencing the motivation towards the certain behaviour. Similar to TRA, TAM postulated that technology usage is determined by BI which is viewed as being jointly determined by person's attitude (A) towards using the technology and perceived usefulness (U) or BI = A + U, however, TAM did not include TRA's subjective norm (SN) due to its uncertain theoretical status (Fred, Davis, & Bagozzi, 1989).

The TAM has been continuously studied. The TAM 2 (Venkatesh & Davis, 2000; Venkatesh, 2000) and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) are the most known extensions that have been proposed. In the former effort, the components that contribute to the perceived easy-of-use have been further discussed, specifically the model proposed 'control' (internal and external—conceptualized as computer self-efficacy and facilitating conditions, respectively), 'intrinsic motivation' (conceptualized as computer playfulness), and 'emotion' (conceptualized as computer anxiety) as anchors that determine early perceptions about the ease of use of a new system. In the latter effort, along with the reviewing eight user acceptance related models, the several derived elements influencing the acceptance of technology such as performance- and effort-expectancy, social influence and organizational facilitating conditions have been proposed. Gender, age, experience, and voluntariness of use are positioned to moderate the impact of the previously mentioned constructs on usage intention and behaviour.

At the same time, usability has been recognized as one of the most important characteristics of systems and products. It has been defined as the measure of the quality of use, when interacting with a product or service or in other words, usability is the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use (ISO, 1998). Consequently, usability testing as an essential part of user-centred design has been widely studied by various research teams (Nielsen, 1994; Virzi, 1997).

To summarise, at this time the user-centred design as a design approach arose rather from the interest towards the technology than actually from the interest towards humans' needs. The usability and technology acceptance have been seen as rather functional technology oriented constructs with focus put on "easy to learn, easy to use and easy to adopt" of already developed technology.

2.3.3 Human Factor

Gradually the field has been taken over also by other adjacent disciplines, such as ergonomics (in the United State) and human factors engineering (in Europe). The research here has much focused on the interaction between people and machines and the factors that affect this interaction (Bridger, 2009). The documentation and information management systems to support office workers have been put very much in focus of development. Various empirical techniques for minimising the problems in human-system interactions, caused by complexity of technical environments have been developed. Research has influenced also by the complexity of rapidly developing military technology (Wickens & Holands, 2000), which exceeded the capabilities of humans operating it and by process automation technologies to foster effective performance and at the same time to eliminate harmful effects (Kuutti, 2001).

At this time, the *Situation Awareness* has emerged as construct with objective to address the needs of military and aviation, in which human operators regularly stressed by greater problem-solving discretion (Carroll, 2013). Later research expanded to other time-critical domains such as traffic controlling, nuclear power plants systems, medical, and manufacturing environments. Several groups have exploited situation awareness from the human cognitive capacity stand, considering situation awareness as a knowledge product and also as a process to achieve this state (Endsley, 1995a, 1995b; Endsley & Garland, 2000; Endsley & Jones, 2001; Endsley, 2006; Endsley, Bolte, & Jones, 2011). Situation Awareness has formally established as a new concept with its definition provided by Mica Endsley (Endsley, 1995a). Topic-related reviews, analysis and critiques regarding the necessity of such new concept and related models also appeared at that time (Dekker & Hollnagel, 2004; Durso et al., 2008; Wickens, 2008).

Situation Awareness is an important construct in the Human-centered design paradigm and it is seen as a driving force to achieve better decision making and performance, though user satisfaction is considered as a side effect, - "As a result of user-centered design we can greatly reduce errors and improve productivity. Along with user-centered design, also comes improved user acceptance and satisfaction as a side effect by removing much of frustration…" (Endsley, Bolte, & Jones, 2011).

2.3.4 Context-awareness

Through the mid-1990s, it is realized that HCI should be a more fundamental paradigm (Carroll, 2013). The World Wide Web pages emerged in the mid-1990s. While the graphical user interactions were still seen as a breakthrough in usability (in contrast with Unix-style tools like ftp and telnet), the new design approaches of displaying and directly interacting with objects have started to emerge. This is also when an era of ubiquitous as well as disappearing computing (Weiser, 1991) and bottom-up approaches in design and development of ubiquitous computing pervasive application and services appeared.

The focus of the research moved to context-aware technologies (Dey, 2001) and the social sciences and cultural anthropology found their place in HCI research (Beyer & Holtzblatt, 1998; Leikas, 2009). The term *context-awareness* was introduced by Schilit (Schilit, Adams, & Want, 1994), where three important aspects of context: where you are, whom you are with, and what resources are nearby were defined. Further, context has been described as encompassing more than just the user's location, because other things of interest are also mobile and changing. Context-aware applications have been defined as software, which is able to adapt according to context. Later other definitions were provided such as for example, a system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task (Abowd et al., 1999). Dey (Dey, 2001) gave more general definition of context, which is "any information that can be used to characterize the situation of an entity". Later numerous context engineering tools and models have been proposed to support context-aware applications. Context-awareness is used to adapt user interfaces (e.g., Motti & Vanderdonckt, 2011), to aid with tasks and work activities (e.g., Prekop & Burnett, 2003), to tailor the set of application-relevant data and to discover services (e.g., Doulkeridis, Loutas, & Vazirgiannis, 2006), and to build various smart environments (Dey, Abowd, & Salber, 2000). Context-awareness is seen as an enabler of ubiquitous computing and personalised services delivery to their users (Perera et al., 2014).

2.3.5 Computer-supported cooperative work

With the growing influence of the Internet on computing, on society and work environment, tools and applications to support the collaborative activities and new paradigms and mechanisms enabling collective activity have emerged. A new field of computer-supported cooperative work (CSCW) is established (Grudin, 1994). Within CSCW, users are seen as active actors in an ongoing and continuous social interaction within various communities, which is shaped by enabling users with tools to make sense of situations and to give meanings to things.

At that time, the *awareness* rose as a research topic to address especially the domain-specific needs of collaborative work environments, including virtual ones (Markopoulos, Ruyter, & Wendy, 2009). There were the need to understand better such aspects as how people gain mutual awareness of work practices and the types of information that is required creating that awareness. In 1995, Carl Gutwin and Saul Greenberg published the first version of their influential workspace awareness framework (Gutwin & Greenberg, 1995), where four overlapping types to create awareness, have been proposed essential to support the groups working collaboratively face to face. These are 'Informal awareness' of a work community (provides with general sense who is around and what they are up to), 'Social awareness' (provides with information that person may maintain about others such as interest, emotional level, attention paid), 'Group-structural awareness' (involves knowledge about people's roles and responsibilities) and 'Workspace awareness', which is integral to previous ones. Later the awareness research has been applied also to other domains such as home, healthcare, education and games, however, with the focus put on supporting social relations and needs (e.g., Gaver, 2002).

The awareness construct studied in scope of CSCW field, and in particular workspace awareness framework, is not directly relevant to this study. However, it can be seen as a good example of domain specific research and also as the way to tackle awareness in technology design.

Ambient awareness displays that came from ubiquitous computing of tangible objects and have encompassed the concepts of "interactive displays" "..with grasping of physical objects.." and ".. ambient media for background awareness.." is yet another, this research influencing concept, that got its origin as a one of the paths in CSCW research. The imaginative idea behind was, that ambient awareness displays would provide information in a format that creates peripheral awareness, when we are aware of some information without focusing our attention on it (Ishii & Ullmar, 1997). Compare to the conventional GUI of display, ambient displays made use of the entire physical environment as an interface to digital information (Wisneski et al, 1998). The several bodies of research have inspired this work. First, is the "ecological" perspective and the theory of "affordances", introduced by psychologists U. Neisser (Neisser, 1976) and J.J. Gibson (Gibson, 1979). Second, there are studies in experimental psychology, especially the notion of the "cocktail party effect"- the ability of a person to selectively move his/her attention around a busy environment (Cherry, 1953) and the divided attention studies of Rensink (Rensink et al., 1997). It was shown that information can be processed, even if it is not in the foreground of a person's attention.

2.3.6 Human-driven design

In late 2000s with progress of mobile phone technology, social network applications and increasing of choice in the smart gadget consumer market and with wide-spread usage of Internet one hand and that people are becoming more and more skilful in the use of technology, on the other, computers have proliferated vastly beyond the scope of tools and become a ubiquitous part of the daily life penetrating into human habits – cars, home appliances, clothing and so forth. In addition, the border in technology for work and leisure activities is blurred. Many were wondering why their work technology is not as advanced as their personal computing systems. According to the Capgemini report employees in 2014 had higher expectations of workspace technology than ever before. The ability to design for user experience became a central issue in human-technology interaction design in this new context.

With introduction of the term human-driven design (Ikonen, Leikas, & Strömberg, 2007; Niemelä, 2014), User Experience (UX) as a research paradigm shifted the emphasis from functional features of human technology interaction (HTI) to the personal quality of interaction to make it more human-centred with emphasis given to affective and emotional concepts, personal values and psychological needs (Leikas, 2009; Rauterberg, 2010; Hassenzahl, 2011). Such issues as pleasure, hedonic values, flow, competence and frustration are emphasized (Seligman & Csikszentmihalyi, 2000; Saariluoma & Jokinen, 2014). Some examples of new approaches in human technology interaction are emphatic design (Koskinen, Mattenimäki, & Batterbee, 2003), value sensitive design (Friedman & Kahn, 2003; Friedman, Kahn, & Borning, 2006), worth-centred design (Cockton, 2004, 2005, 2006, 2008) and the design for pleasure (Jordan, 2000; Bonapase, 2002). Emphatic design is originated from industrial design and it addresses the creative needs of designers at the early phases of product development, when a range of design options is still open. The research methods provide designers with understanding about how users experience the surroundings and the people in it including themselves. Value sensitive design brings forth moral issues in product design. Design methods emphasize ethicality as an important point for the design and such values as privacy and non-discrimination as well as control (Leikas, 2009). In worth-centred approach the emphasis of the design is put on the outcomes of interaction with technology, the 'worth' that people consider in relation to products and services i.e. things that are 'worthwhile' for the user, and irrespective of ethical norms, trends, fashion or etiquette. Worth-centred development gives a measure of the benefit of technology. The design for pleasure is based on the pleasure framework, where the dimensions of pleasure may relate to sensual feeling, social enjoyment, emotions and ecological and esthetical aspects.

In spite of various approaches emerged, the User-Centered Design is a commonly used design approach to master human technology interaction. Various not necessary contradicting approaches to analyse the motives of user/human interaction with technology can be found in the disciplines described previously. The cognitive schools of HCI based their analytical work on Alan Turing's model of human mind. User has been investigated as an information processing system (e.g., Card, Moran, & Newell, 1983; Laird, Newell, & Rosenbloom, 1987; Anderson, 2002; Meyer & Kieras, 1997) though a little attention has been paid to emotional interaction, motives and culture (Saariluoma & Oulasvirta, 2010). The philosophy of activity theorists in HCI (e.g., Kuutti, 1996; Nardi, 1996) is grounded to needs, however, driven rather by organization than by certain goal of individual. Being user means utilising technological artefacts in an activity to achieve a goal. However, the mental aspects are not much included in explanation of human action (Saariluoma & Oulasvirta, 2010). The phenomenology rooted to philosophical studies of Husserl (1913/1982) and Heidegger (1927/1962) has focused on how technology can be designed as ready-to-hand tools that become transparent to the users' material dealings with objects of concern. A phenomenological understanding of user experience turns the awareness from products to a first-person perspective on the ways in which people engage with objects i.e. experiences and meanings. The analysis of human-computer interaction is opened by terms of intentionality, ontology and intersubjectivity (e.g., Dourish, 2004; Fällman, 2003). However, the phenomenology is lacking of concrete methods of using their approach in interaction design (Saariluoma & Oulasvirta, 2010).

The understanding of what actually is the "user" of a technological system has obviously a strong influence on the systems to be designed. The notion of 'user' in technology design has undergone a number of changes during the last decades along with the interpretation given by different research communities discussed previously. As nicely expressed by Kuutti (Kuutti, 2001) a "user" has undergone a number of changes from user as a rational cog in the organizational machine, user as a source of errors, user as partner in social interaction towards the user as a consumer. Furthermore, it has been shown that the concept of usability has been re-articulated and reconstructed almost continually, and has become increasingly rich. It is started with the slogan "easy to learn, easy to use" (Carroll, 2013) and evolved into subsume of qualities such as fun, worthiness, aesthetics and many others discussed previously.

2.4 Discussion

Although the concepts of the user, usability and user experience have undergone a number of changes and became richer and multidimensional, the perspectives of user, where the aim is to focus on the human needs and the characteristics which define his/her as a user, should be yet emphasised and stressed more. In this sense, for example, *user psychology* as a design discipline should be brought more in the design. The goal in user psychological research is to explain phenomena typical to interaction between people and technology. The central in user psychology research is identification and analysis of technology use related phenomena in terms of psychological theories (Saariluoma, 2010). This discipline stresses the cognisance of psychological goals, needs, limitations and preferences of people in the design (Saariluoma, 2004). Such analysis and explanation require explication of the phenomena and related concepts in the language of psychological theory, concepts and principles. Explanatory user psychology provides technology designers with a tool to build a close connection between psychological research and design solution.

In practice, however, psychology does not necessary provide designers with unified explanatory framework which is able to answer all the questions the designer may have. Instead, different types of design questions must be addressed using different types of explanatory frameworks (Saariluoma, 2004). Furthermore, user technology interaction is so complex that multiply explanatory frameworks are needed to be utilised. Some of the most important explanatory frameworks, which enable to explain many user-technology interaction problems, are *capacity and mental contents and emotions* (Saariluoma, 2004).

The capacity- and content-based frameworks are not contradictory, but they provide answers to different types of questions. While the target of capacity based analysis lies in the workload of interaction and related performance of individual, the target in the content-based analysis is in the information contents of involved mental representations. Further, the capacity-based human behaviour explanations are typically bounded to the to the simple perception processed and present situation, while content-based explanations enable taking into consideration such aspects as representations of future events, individuals' intentions, goals and needs (Saariluoma, 1997; Kujala, 2010).

Explaining by the *capacity* of human information processing system, limitation in working memory or attention is one way to explain and address the interaction problems (Shannon, 1948, 1950; Miller, 1956; Broadbent, 1958). These limitations have been studied by decades as explanation to human performance and errors (Allport, 1980, 1993; Allport, Styles, & Hsieh, 1994) and they are also leveraged in the interface design (e.g., menu structure, notifications and colours). The capacity-based explanations are extensively used for example by Endsley in her studies related to human performance when doing with time-critical systems (Endsley, 2006).

The concept of *mental content* may give designers an alternative and complementing perspective to interaction compare to capacity-based explanations. Modern psychology accepted mental representations as its basic analytic tool in the early 1970s (Newell & Simon, 1972). Mental content means the content of a mental state such as a thought, belief, a desire, a fear, an intention, or a wish[1]. A mental model (mental representation of content) is a kind of internal symbol or representation framework which is used to describe how such mental content exist in human mind as representations (Fodor, 1987, 1990; Newell & Simon, 1972; Saariluoma, 1997).

The construction of mental representations is referred to as a process of apperception (i.e. adding to our perception) (Saariluoma, 2003). The concept of apperception was introduced by Kant (1781/1976) in his analysis of pure reason. In a modern psychology, this process is known as a mental processes in which a presentation is brought into connection with an already existent and systematized mental conception (schemata), and thereby is classified, explained or understood as a whole (Runes, 1983). As discussed earlier, in Piaget's theory of development, by assimilation children construct a series of schemata, based on the interactions they experience.

A concept of *schema* is important in understanding of mental content. It is a pattern of thoughts or behaviour that organizes categories of information (contents) and the relationships among them. Schemas influence attention and the absorption of new knowledge *to form awareness* as discussed in Section 2.2. People use schemas to organize current knowledge and to provide a framework for future understanding of new knowledge (Neisser, 1976). Things that fit into individuals' schema are more likely noticed, in fact the *expertise research* is relied on apperception process of previously learned thought models and mental representations (e.g., Simon & Chase, 1973; Saariluoma 1990; Simon 1969; Ericsson, 2006).

From content-based point of view, the familiar models are not only recognised but also new situation-specific content is organised in the subjects' internally consistent representations, which make the elements of representation functional i.e. in an efficient economically "make sense" way (Saariluoma, 1990, 1992, 1997). This for example explains the fact that, based on the content-specific principles, capacity-limited human chess player can play as efficiently as a computer in finding the best move. Thus from human-technology interaction perspective, question related to "sense making" may emerge when trying to understand why people do what they do. To sum, the basic assumption of the

[1] https://plato.stanford.edu/entries/content-narrow/

content-based analysis of human action is that mental representations influence human behaviour and it can be used to explain human behaviour.

The analysis of people schemata is important because it allows to understand the motives, feelings and thoughts people may have, so that the product can response and being coherent with existing schemata. Mental representations may entail conscious and subconscious parts. Conscious part can be verbally expressed while subconscious not immediately. Such methods as questionnaires, observations and interviews are essential to understand conscious and subconscious parts of user experience as a mental content (Saariluoma & Jokinen, 2014).

Other examples of explanatory frameworks are the ones that aim at explaining of interaction taking into consideration individual differences or cultural issues. The individual differences may relate for example to age, gender or personality type. While cultural aspects may relate to the rules and precludes existing in the society (Saariluoma, 2004).

Complementing the exiting studies with the aspects of *awareness-aided technology design* and explaining it in a *language of psychological concepts and theories* connected to the mental content is a progressive step in the direction advocated by user psychology. To be able to do this, applications and services should be developed on the grounds of human dimension, that is, on the understanding of what information makes up the awareness while interacting with technology. Therefore, *a model* is needed that would generate adequate *awareness requirements*, i.e. well-defined requirements for the design that make it possible for developers to effectively employ knowledge of the awareness dimension in the design of the given system or service.

This human dimension of awareness in technology design is not yet as well understood as technical dimensions of complex intelligent technologies. Scientific foundations for designing the awareness dimension and especially practical models for applying these in the design are still missing. That is why, here the focus is put on developing awareness model for solving questions developers face with the human dimension of intelligent technologies.

Looking again on the relevant existing research in the area of pervasive ubiquitous computing environment, somehow related terms to this research are the concepts of *'context-awareness'* and *'situation awareness'* discussed earlier. The terms context awareness and situation awareness are used interchangeably by some authors (e.g., Cimino et al., 2012; Ye, Dobson, & McKeever, 2012). However, there is undergoing discussion to distinguish the ones:

- The differentiation between situation awareness and context awareness occurs in the abstraction level of their models and in the level of a particular context's granularity and representation. (Nwiabu, 2011)
- Events—generally perceived via sensory devices—are subject to a primary information structure related to location (where), identity (who), activity (what), and time (when). The underlying observation system uses this information to determine the why of a given situation. (Dey, 1999)

- In contrast, situation awareness is concerned with the knowledge state—high-level information—that explains what an application domain is experiencing at any given moment. (Lopez & Alcaraz, 2013)
- One way to progress with distinguishing of these two concepts is to look on them from the point of subject who performs situation awareness – human or computer. (Kokar et al., 2009)
- Awareness is the state of knowing about the environment in which you exist, about your surroundings, and the presence and activities of others. (Wisneski, 1998)

These terms are related, however, there is an important difference between them. The difference lies in their application. First, situation awareness is related to human ability to perceive the situation, while context-awareness is related to the ability of computing system to understand situation. The second important difference is related to the usage of these constructs. While the context-awareness aims to enable better service delivery to its user through proactively adapting use and access of information, physical resources and modality feature of human-computer interaction process with respect to available context information (Soylu et al., 2009; Schmidt, 2012). In contrast, situation awareness is the perception of elements and "events" in the environment related to human - is simply knowing and understanding what is going on around or as well put by Lopez – "understanding what is experienced by the application domain, however, from user point of view". This brings us to awareness – the *subject of this study*, which complements other forms as visualised in Figure 5.

While the methodology towards the developing of context-aware applications for various domains such as smart home, public safety and security, logistics, design and information management have appeared (Dey, 2001; Sousa, 2006; Hong, Suh, & Kim, 2009; Perera et al., 2013), there has been a little focus put to support the human awareness in this new context (Chen & Rashidi, 2012).

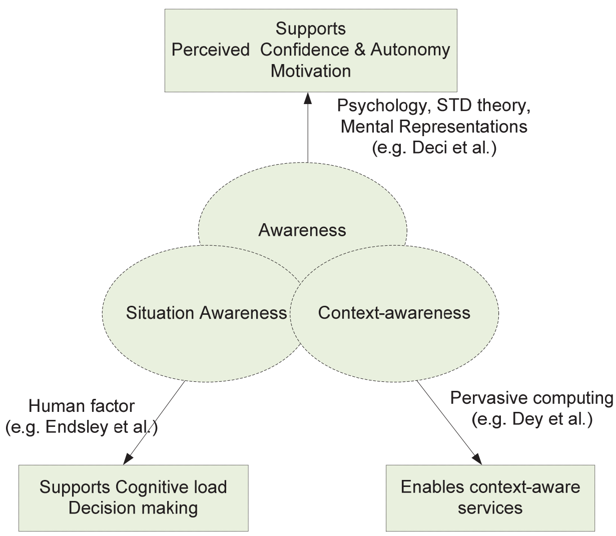

FIGURE 5 Types of awareness in HCI research

As discussed earlier, the model proposed by Endsley addresses the needs of human situation awareness, however, her studies are mostly concerned with complex dynamic time-critical systems and the support required in situations "when something is happening and needs a decision" and the decision should be made by human actor. It is very much bounded to human perception processes and present situation. However, interacting with technology not necessary always involves critical events, high information load or extreme dynamicity specific to military or nuclear plant systems. Of course in everyday situations, while interacting with technology and reusing Endsley three level of awareness, all this can occur, however, in many cases future events and the usability in forms of motivation, individuals' intention, motives and needs are something that is equally important when designing new technological services and products.

The recent human technology interaction approaches such as value sensitive design highlight the importance of such values as responsible autonomy and ability to control the technology. However, there is a little on design constructs provided to support the designer in implementing these features in developing of new products and services.

In this research we aim at extending the existing studies in the field by looking on *Awareness* further according new context of everyday modern pervasive open technology-based systems. SDT theory of inner psychological needs, user psychology of awareness and related psychological theories and concepts provided us with a foundation towards a conceptual framework of awareness-aided technology design. The theoretical framework is approached through the examination of various open and semi-open professional and leisure domains such as smart home, aircraft assembly, future product design tools as well as medical emergency management. *As a result of this research*, first, the importance of incorporating of *awareness as an inherent design feature* in mastering of modern technology is highlighted; second, the *design ontology in form of vocabularies and design questions* as a tool to facilitate product designer in mastering of awareness-aided products and services is defined.

3 SUMMARY OF DOMAIN SPECIFIC STUDIES

In each study, we examine modern technology-intensive eco-systems of intelligent products, services and applications. We approach to the design of awareness-aided technology from end user point of view and needs, by investigating and designing of respective artefacts that may contribute to the perceived feeling of awareness, confidence and autonomy and thus positively improve the overall acceptance of the system. In each study, depends on the context, extensive user research facilitated by organising numerous workshops, questionnaires and monitoring and analysing the users of the systems in action is performed. All studies were aimed at the understanding of awareness and what it gives to the user.

The focus in each study is put on the particular aspect of awareness hypnotised based on user requirements and literature research:

Smart home context The aggregative intuitive user interface and home-domain-specific models have been studied to connect and situate various information sources, services and environmental items and personalities with aim to support end user as a shaper of own living environment.

Cooking guide study The awareness and the perceived feeling of confidence and autonomy have been approached from the perspective of learning as well as understanding about functions of smart cocking application.

Aircraft assembly line scenario The focus is put in particular on the aspect of the global awareness that can be implemented as facilitating factor towards the acceptance of the technology in the complex context of various technological systems-of-system interacting with each other. Such global awareness aims at providing various actors in the systems with better overall picture and thus better understanding the status of the assembly floor. Consequently, this allows optimising and changing working processes. The methods based on machine learning algorithms and anomaly detection are not capable to accomplish this need alone. There is a need for visibility. The knowledge of the domain and the involvement of human reasoning is necessary in this study case.

Medical emergency response The research on awareness is complemented with studies on the "simplicity" addressing complexity of heterogeneous multi-actor context of emergency management environment and the role of human expertise in this context.

Product conceptualization study We look at the designer itself during the initial process of conceptual product design and the relevant tools and practices used during this process. Moreover, the domain specific knowledge model is studied. We aimed at the combining knowledge about product under design, product usage environment, trends and societal aspects and the designer itself. Addressing the designer need of awareness and perceived confidence, the aspect of the content delivered to designer rather than the 'interface' in its traditional meaning, has been put in focus.

In the following, domain studies are presented in more details. The challenges faced by the domain and how they are addressed in the respective studies are explained.

3.1 Personal Applications and Services – leisure domain

In this research, the problematics of acceptance of smart home technology as well as personal sensory based knowledge-extensive intelligent applications are investigated.

3.1.1 Smart Home

Smart home technologies include sensors, monitors, appliances and various other devices such as fridges, washing machines TV, and heating systems that networked together to enable automation as well as remote control of domestic environment. There is a vision about "smart home" that with recent technological advances in pervasive computing, wide deployment of RFID devices, wireless sensors and Internet services, in the future our homes will be so automated and smart that we will barely need to think about everyday tasks. Accordingly the majority of smart home research has been centring already a decade to implement this vision and to apply ubiquitous computing technology in the automating home systems and scheduling home appliances (Brumit et al., 2000; Taylor & Swan, 2005) or in providing support for service developer and end user towards the programming of smart home services and applications (Jahnke, 2002).

This vision is around already quite a while and number of good and effective services and applications can be found in the market, however, smart home is still not here. Actual level uptake of smart home is low and it is largely dominated by smart internet-connected TVs (Harms, 2015). It is seen that there are several reasons behind. They are related to interoperability, security, complexity and general usability of smart home as well as the lack of awareness about existing technology. Product developers are devoting their time to portrait their technology to various systems and protocols, thus consumers are confused about the technology to invest in.

This study (Paper I) addresses the complexity of ‘technological’ interface to smart home products and services and also the lack of attractiveness and understanding of smart home. Current Interface to home technology is complex, distributed over various devices and lack of cognitive comprehending and appreciation.

Contribution of this research

The researched and developed VantagePoint application reported in Paper I aims at empowering and inspiring user to supervise own home and thus contribute positively on the uptake of home technology.

The developed aggregative visual tool (see Figure 6) enables user to observe, manipulate and understand the state of the house and interact with home data letting the user query house information in real time. The proposed technology is inspired at this time *popular computer games* such as “The Sims” and “SimCity” and it explores different types of visualization techniques, - isometric perspectives, 2D-3D views, and spatial relations between objects. While two-dimensional view aims at providing more accurate model editing operations, the purpose of the isometric view is to visualise home model in a more impressive and effective and familiar way. VantagePoint provides a basic library of icons representing devices, furniture, persons and interior decorations that are *customisable* and can be *easily drawn* using available open source tool and imported to VantagePoint, to make smart house interface *to be unique for each person living it.*

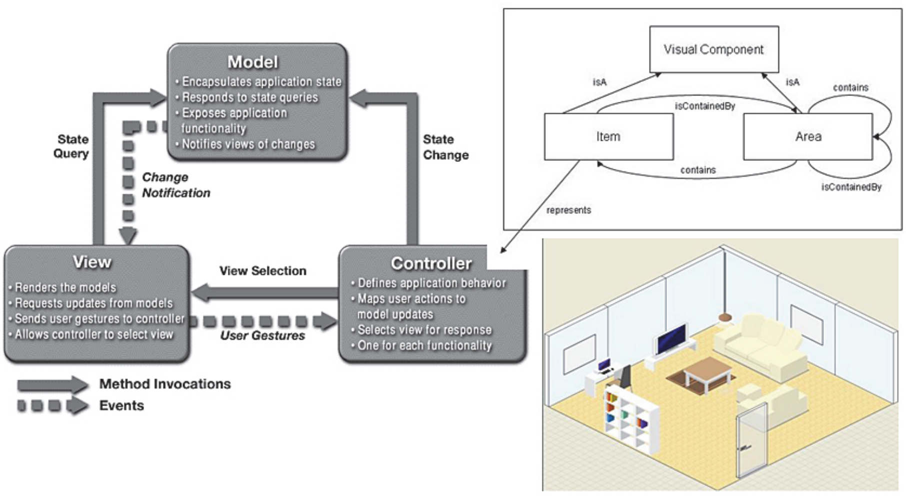

FIGURE 6 VantagePoint tool

During our research, apart from the visualization and the attractiveness of user interface, we have experimented with various contextual knowledge models required to achieve and to support the perceived awareness of the house. The extendable *knowledge models* are defined to describe various aspects of living environment such as the details of the house itself, areas and rooms, materials and furniture as well as the services and technology situated and used at home. We learnt that the respective *home domain analysis* is necessary to achieve true perceived awareness of the house.

Semantic technologies have been extensively studied as a part of this research. Ontologies allow structuring and describing various aspects of domain in an expressive way. Reasoners thus facilitate deriving of new information and querying of domain knowledge.

The technology is validated with several use cases from different application domains introduced and co-designed with end users such as home maintenance in an everyday use and the support for the ambient assisting living services. The tool has been offered for testing to the group of individuals with different profiles and technical skills such as researchers within VTT and also workers of municipalities - partners within AmIE, Ambient Intelligence for the Elderly, international project consortium. The feedback was very positive. Especially the possibility to model own apartments introducing rooms, home appliances and other details of living environment have been found attractive. The tool has been also demonstrated interactively in "Good Age" Expo 2009. The main audience was elderly adults, their relatives, caregivers and industrial representatives manufacturing the products for elderly. As expected the feedback was heterogeneous, more positive from visitors which are skilled in technology, daily using Internet, sometimes Skype and more cautious from other group that generally is not comfortable with technology. However, all has acknowledged that tool is interesting as a solution for the smart home of the future and most of visitors has admitted that they would like to have something similar in particular to maintain own house history (keep digital manual with maintenance instructions, history of purchase and repair, etc.).

The "Good Age" expo demonstration has led us to the close cooperation with Alzheimer association. Consequently, the VantagePoint software has been leveraged to develop a Web based "Muistikoti" application towards the addressing the limited awareness of the potential of existing assistive technology for adults suffering from Alzheimer disease (Niskanen & Kantorovitch, 2011).

3.1.2 Interactive Cooking Guide application

In this study (Paper II), the previously developed technology and research have been extended to study the elements of awareness in the context of knowledge-intensive personal mobile applications.

Cooking guide is an example application that is heavily depended on dynamic context-sensing information (Vildjiounaite, Kantorovitch, & Kyllönen, 2011). The Cooking Guide may run in a touch-screen device, for example, and it helps the user during meal preparation by providing detailed cooking instructions. Cooking Guide is designed to be able to adapt its behaviour according to the context information such as available smart appliances augmented by various sensors, output devices, and user's cooking experience, thus each step can be potentially performed in a different way. Cooking guide is a true effort towards the contextual rich dynamic proactive knowledge-based application. Proactive knowledge base is built from the sensors augmenting the objects in use, surrounding devices and user profiles. Sophisticated data mining algorithms, rule based mechanisms and user-learning techniques facilitate contextual awareness and adaptability towards the assistance and end user ambient support.

However, when evaluating the ideas of sensor-rich, ambient computing environments to ordinary users, non-technical people, in particular, express anxiety when they find themselves in situations, where they feel that their behaviour is being monitored and analysed by technological systems which they do not fully understand or don't see the value (Feeney, 2008). Such negative reaction to applications that use sensing technology sets a challenge that needs to be addressed.

The explanation interfaces have been extensively studied towards the increasing user acceptance of technological systems in a number of fields such as expert systems (e.g., Southwick, 1991), intelligent tutoring systems (Sørmo & Aamodt, 2002), data exploration systems and recommendation systems (McSherry, 2004; Pu & Chen, 2007). In relation to intelligent physical environments, the necessity to support the functionality, that makes system's reasoning process visible and insight of the system comprehensible, has been acknowledged relatively recently (Callaghan, Clarke, & Chin, 2008; Kofod-Petersen & Cassens, 2011; Blomqvist, 2014). Existing approaches to visualise the rules of the system are targeting mainly a data exploitation professionals. Accordingly, common for the developed techniques is that they rather support the categorization and browsing of potentially complex rule bases, while the ground to the world of physical devices and situational context, fast assimilation and intuitive visualization important for non-technical end user are left beyond.

Contribution of this research

The proposed approach, VisuMonitor, reported in this study, supports the users of Cooking Guide application by providing various visualization views that show the proceeding of cooking processes and explain the functionality and behaviour of the system during different cooking activities, thus improving user awareness and education and thus enhancing the acceptance of the technology. The tool communicates with the workflow engine of the cooking guide application to retrieve the necessary information needed for workflow visualizations. In addition to static and dynamic workflow representations, VisuMonitor may also provide with such information as the different resources needed to complete cooking activity or information related to functionality and behaviour of the cooking guide system. More specifically, the functionality of VisuMonitor tool supports user awareness in several ways:

- Showing practical information related to the cooking process such as the proceeding of the cooking process from one-step to another, the information provided by different sensors and the usage of cooking utensils;
- Providing explanations related to the functionality and behaviour of the cooking guide system, such as for example, why the cooking guide application decided to change from speech to textual guidance in some point of the cooking process;
- VisuMonitor may also educate the user by explaining why the particular recipe or certain ingredients are recommended such as for example, due health reasons, diseases, dietary or recent blood test.

By integrating the *domain data* acquired from workflow engine and Cooking Guide, VisuMonitor is able to produce a global view of a cooking process. The compositional structure of the VisuMonitor infrastructure is shown in Figure 7.

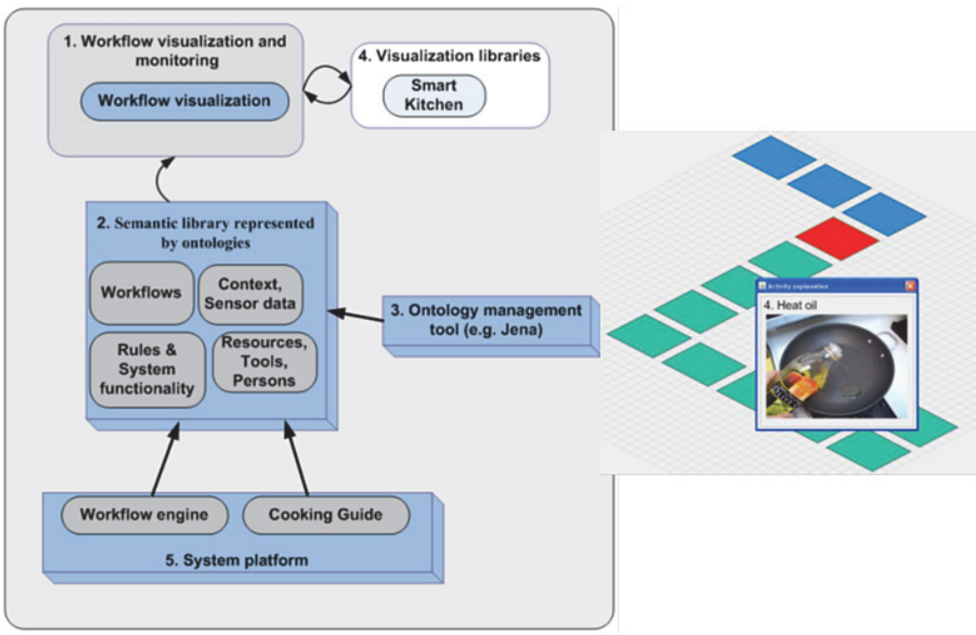

FIGURE 7 The compositional structure of the VisuMonitor

The proposed technology utilizes semantic technologies to represent workflows and the context of Cooking Guide application i.e. *respective domain model*. Domain model contains the detailed description of user (preferences, interests), cooking environment (kitchen, utensils) and the domain (cooking recipes, tips). The use of semantic technologies is especially pertinent with such applications as the VisuMonitor where complex and heterogeneous data is gathered from multiple sources and it has to be presented to the users in a comprehensive way. The utilization of semantic technologies provides also an intelligent way to define and use rules that guide the behaviour of the application.

Different cooking processes executed with Cooking Guide are modelled as workflow descriptions. Cooking Guide is tightly integrated with an application workflow engine, which manages the workflows that are executed in cooking processes. The executable workflows are described with an XML-based serialization format known as XPDL (XML Process Definition Language).

Visualization- and user interface-design form such an important part of the approach, hence several user interface mock-ups were created and evaluated before the actual implementation work is started. The purpose of the initial evaluations was to ensure that user perceive the created views and explanation dialogs as informative and comprehensible. Our visualization approach aimed at linking a contextual world of physical services and devices used by application, simple and intuitive workflow visualization graphics and quickly comprehendible connections to real-world cooking artefacts. As an example an overall view of the cooking process, in which the proceeding of the cooking flow from one-step to another is illustrated in Figure 7. The already finished activities are depicted with blue boxes, the current step of the cooking process is emphasized with red colour and the green boxes represent the activities that have not yet been started. The user is able to acquire more detailed information about different activities by clicking the boxes representing the different steps. The purpose of different visualisation views is to enhance the general comprehension of cooking processes and to provide users of product with perceived feeling of competence and comfort when interacting with technology.

Prior the detailed design and the development, the initial prototype has been evaluated with different end-user groups (Vildjiounaite, Kantorovitch, & Kyllönen, 2011). User group is consisted of 14 females and 10 males, working in different areas (biology, physics, tourism, finances etc.), but not in computer science. Participants belonged to three age groups: elder than 55 years old (3 females, 4 males); younger than 25 years old (6 females, 3 males) and between 40 and 50 years old (5 females, 3 males). The cooking application was evaluated in several cooking contexts such cooking new dish, cooking known dish, busy cooking in a company with children and friends and cooking outside of the home. The results proved that VisuMonitor enhances the understanding of application behaviour and makes the functionality of Cooking Guide more appreciable for the user. The prototype capability to explain own behaviour and to allow easily altering (disabling/ enabling) of most socially intrusive functionality was highly appreciated by all subjects, and some of them wanted to have larger number of easily accessible controls. The prototype capability to postpone audio messages until a break in a conversation and to apologise for interruptions, when the messages cannot be postponed was liked very much. The suggestion of particular recipes and health tips based on user preferences has been found useful.

3.2 Production Line Environment – professional context

In this study (Paper III), we have focused in particular on the aspect of the global awareness that can be implemented as facilitating factor towards the acceptance of the technology in the complex context of various technological systems-of-systems involved such as in case of assembly line environment[2]. In addition, the mix of automatic and semi-automatic functionality in assembly systems is seen as an additional challenge to be addressed. It makes this case different from autonomous time critical systems studied in the course of human factor research. For example, it may happen that design evolutions coming from design office induce some delay in installation operations that should be resolved by human operator.

The complexity of modern production lines and the dynamic nature of the domain make it difficult to maintain their progress during the actual execution due to several reasons. In such processes, various teams with different areas of technical expertise are involved in activities to be performed synchronously. These activities are not always sequential. There is an increasing complexity of subsystems to assemble, along with the fact that supply components come from various industry parties and players. One activity in the process may influence another, therefore the coordination is required. There is heterogeneous information all over the shop floor and interdependencies exist within the information spaces. There are external factors affecting operational status, such as unavailable or multifunctional equipment, delay in supplier components or changes in the human resources involved.

The examples of coordination solutions discussed in the literature are for example, the Andon system by Toyota (Monden, 1993), LiveBoard (Elrod et al., 1992), Trauma's center Whiteboard (Xiao et al., 2001), iLand (Streitz, 2009) and iRoom (Johanson, Fox, & Winograd, 2002). Further, a study presented by (Laborie, Chatty, & Reyterou, 2005) exploits the conceptual environment composed of large public displays to facilitate the collaborative process in the aircraft final assembly lines in Toulouse. There are also other applications that have exploited large displays to make information on activities available to a community of users (see discussion in Chapter 4). These systems are developed with the objective of supporting a broad spectrum of group activities, creating a common information space and providing the background awareness on activities that a number of various groups/teams are involved in and tasks that have been accomplished. Current existing tools are based on aids such as graphs, charts and photos may not facilitate the desirable communication of progress in a complex technology-rich environment in a desirable detailed way. Moreover, the acceptance of such sensory-based functionality on the shop-floor is other important issue to address. The difficulty is mainly related to the increasing complexity of sub-systems to assemble, the increasing amount of assembling teams

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[2] *The details of the design as well as the evaluation and feedback given on the developed technology are not fully presented in this research paper due to the "security policy" of EADS*

involved, and the caution of actors regarding the usage of 'monitoring' aspects and trust to the monitoring system.

Contribution of this research

In this study, the realistic scenario provided by EADS for research purposes has been analysed. It involves two operators who have received a work order to tighten two electric harnesses onto an aircraft panel. Both operators work simultaneously on the same work order, which may contain several subtasks. The operators are also equipped with tools, a nomadic device and a smart tool (e.g., a smart rivet gun, a smart glue gun or a screwdriver). The nomadic device guides the worker through the workflow and the smart tool is used to tighten assemblies. The scenario also includes a support team that monitors the assembly procedure remotely and reacts in case of unexpected events during the process, and a station manager who is in charge of the overall organisation of the assembly line. More information about the background to the scenario can be found in (Hugues & Golenzer, 2010).

Leveraging recent advances in semantic technologies, 3D visualisation techniques and contextual workflow modelling mechanisms, SPMonitor software provides intuitive and convenient visual aids to support various actors involved in overall processes running on industrial production lines (see Figure 8). To achieve the desired awareness at the assembling line, the domain analysis and the requirements to the proposed technology have been acquired facilitated by bi-week discussion workshops with EADS team.

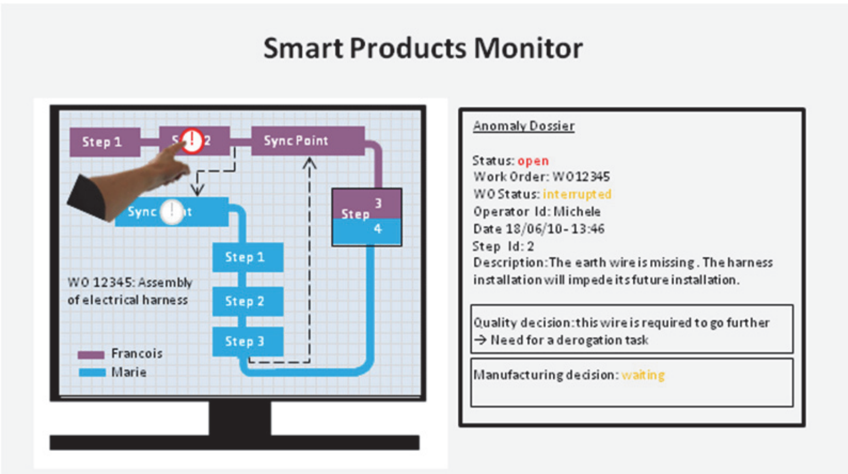

FIGURE 8 The SPMonitor tool in use

By managing the interdependencies between numerous activities running concurrently, domain model is designed with aim to provide support for:

- Combining, storing and visualizing of various statuses such as status of equipment (ready, in test, etc.) and tasks (complete, scheduled, delayed, etc.);

- Scheduling and representing of various assembly tasks as well as the usage of resources and tools, and updates providing contextual views to operators, support teams and managers responsible for the overall processes on the line;
- The tool can be used as an "extended desktop" so that operator can see more details on scheduled task, for example, linked to 3D animations, the videos, the textual procedure, the current instruction in the procedure and other attached documents helping to accomplish the task. The information is optimised by presenting it according users' preferences.

In addition, from a scientific point of view, this research contributes with the novel approach to the modelling of semantically annotated contextual workflow-based production processes. Semantically described workflows provide powerful reasoning potential to align information spaces of productive lines and enable richer visualisations showing comprehensive data in a single – "digital twin" view. Various contextual views, empowered by 3D functional graphic elements provide the value for the coordination and control of production lines, thus contributing to the better acceptance of the entire technology based assembly system. The visualisation libraries and semantic descriptions can be again extended with domain-specific needs. SPMonitor has been evaluated with real users (workers at EADS and VTT designers). The tool has been rated very high for the clarity of its visualization views and overall usefulness.

3.3 Medical Emergency Response – professional context

In this study (Paper IV), the 'Awareness Model' for medical emergency case is investigated. We complement the previous studies with new knowledge on engineering awareness in particular keeping in mind an open heterogeneous dynamic context of emergency management environment. Moreover the role of human expertise in this context, as well as the developer support towards the developing applications and services for the open multi-technology eco-systems of products are addressed. This study can be seen as a more complete effort that implements the lessons learned in the previous case studies. The knowledge models and respective knowledge based architecture facilitating the development of awareness are mastered by examining various design-view points, actors involved, and the domain specific aspects such as standards and accepted work practices in the domain as visualised in Figure 9. Moreover, the way to achieve the "simplicity" in the designing of support for such obviously complex and open environment is studied.

Contribution of this research

Disasters per se is the intensive subject of research, with one of the focus points being the development of solutions on how to manage inherent complexities and uncertainties of disaster situations and also on how to provide the 'right' information for professionals in this complex context (Hristidis et al., 2010; Leppäniemi, 2012; Liu, Brewster, & Shaw, 2013; Blomqvist, 2014). Our contribution to disaster research is to introduce the clinician's point of view, which shifts the paradigm from research on uncertainty to user-driven research on how to increase certainty enabled by awareness of the state of the person affected by emergency event in the first instance (we call her/his as a patient in this context). Our contribution to the state of the art is about a way to extract the "simplicity" hidden in a complexity of emergency environment. We achieve this by applying the patient-centred awareness to derive the requirements for patient safety during emergency medical response.

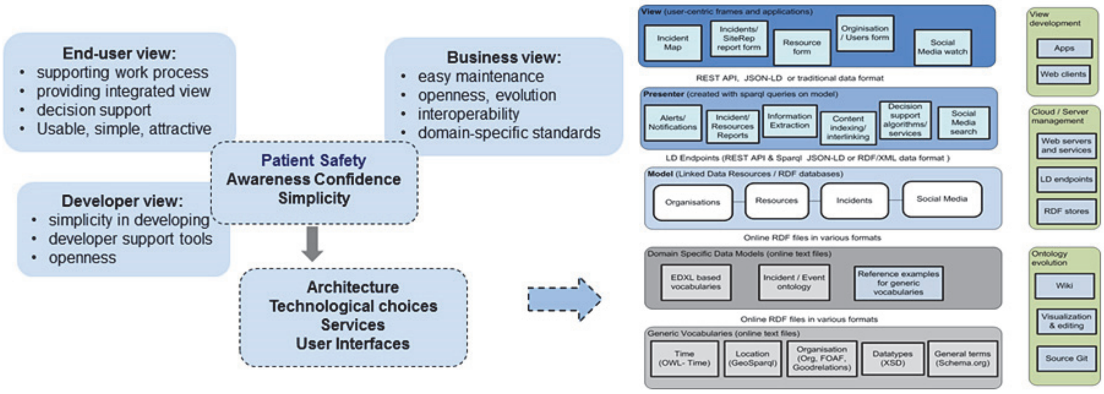

FIGURE 9 The software engineering views

The methods for the collection and analysis of emergency response towards the creation of domain model involved literature and clinical practice reviews and face-to-face interviews with stakeholders (e.g., the London Ambulance Service, the Vienna Red Cross, and the Sofia Military Medical Academy). This led to the codification of the principle five spaces, related actors and their actions directly linked to medical emergency response as discussed in Paper IV. The emergency responders working in each of these five phases/spaces have sets of patient-related tasks, which are the same, irrespective of country or type of incident. These tasks form the basis for the generic set of requirements for technology and situation awareness and decision supports. The more the actions across the spaces are interlinked by effective information sharing technology and the more provisions for mutual visibility, early situational awareness support are provided, the more the phases are enabled to run in parallel, therefore saving time and becoming more effective in saving lives. A Common Information Space introduced to maximise the information outcome across five operational conceptual spaces of emergency medical response, decision support points and information-sharing patterns constitute the human awareness model.

Thinking of human decision making, when first responders arrive at a mass incident, they immediately need to deal with a variety of victims/patients with a variety of needs. It can be challenging to remember all procedures under stress and time-pressure. In addition, the level of expertise of the first responder could vary (medical vs bystander), therefore depending on the profile of the user various levels and types of content (e.g., triage instructions) have been codified to support the decision-making. The requirements to the way the expert knowledge, such as rules and instructions, are linked to the task at hand and the role of the actor, as well as to availability of domain knowledge such as emergency incident types, specific events and patient severity have been set accordingly. It has become clear that information visualisation-based aid should be simple, intuitive and very structured, as well as easily customizable being acceptable in various countries and emergency management systems.

Moreover, during the discussions with experts, the time aspect of decision making under the pressure of crisis situation was emphasized, however, it was pointed out that decision makers often rely on long experience and expertise and extensive availability of information rather than "right information at the right time" and careful analysis of recommendations provided by the system. This aspect was taken into the design by maximising of visibility of available information thus leading to better confidence in decision making supported by awareness. The Awareness model has been positively evaluated as a part of overall functionality of the developed decision support system (evaluation results are reported in (Concorde, 2017). The ability of the system to explain its own recommendations were found in particular useful.

3.4 Product Conceptualization – semi-professional context

In this study (Paper V), concept of awareness and the respective support of human confidence and motivation are approached in a slightly different context, which is a digital work environment of professional product designers.

The creation of new products and services is an everyday activity for many industries, often assisted by professional design studios (as illustrated in Figure 10). The initial stage of the product design process typically begins with the initiation of a design brief. A design brief may be a vague statement provided by the client, or it may be a more detailed design specification. The early, conceptual stage of the process is dominated by the generation of ideas, and the term 'ideation phase' is used to denote this process. The ideas are subsequently evaluated against criteria set out in the design brief, and agreed with the client. The design process can proceed in many different ways. When developing new concepts, existing solutions and ideas that are already in the market are considered. It is therefore critical for any product development team to be aware of past solutions, market data, and emerging technologies, in order to avoid duplication of effort and instead to stimulate creative thinking.

During the research phase, it is typical for designers to use various supporting digital tools to search and save a vast quantity of visual and other data. The interviews and questioners-based research with professional designers revealed that designers rely on resources available from the consultancy and the client's own database, such as documents or sketches produced in the course of previous projects, as well as a range of external information sources such as electronic books, images, music, online design magazines and image collections (e.g., Getty, Flickr, Co.Design, Yatzer, Designboom, Design Observer and Pinterest). In addition, general-purpose search engines such as Google were mentioned as a daily source of information, regardless of the type of project. Designers may also create digital or physical sketches, which can be photographed and uploaded to the project space.

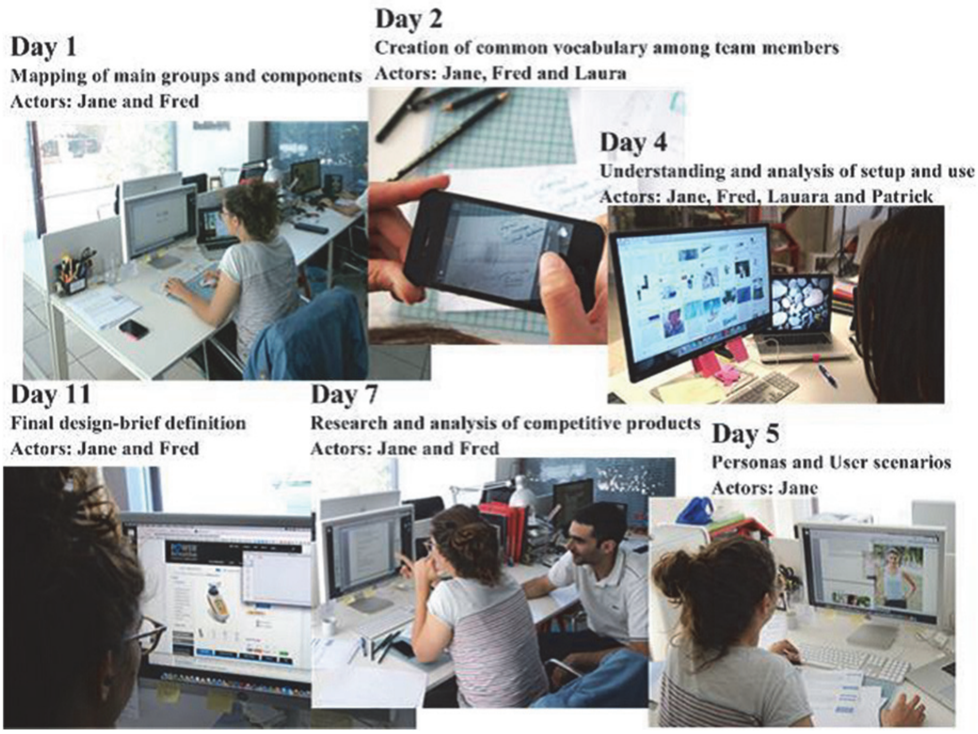

FIGURE 10 Design activities

Moreover, due to the interdisciplinary nature of the design process, a semantic gap exists in the use of terms and concepts. Designers and clients have to generate and exchange ideas. In addition, a variety of tools can be used during this process, which results in the producing of an enormous amount of interrelated heterogeneous data, all of which adds to the challenge in grasping the existent content. Furthermore, it is paramount to ensure that the new software is intended as a tool to enhance the creative process and should therefore not distract from the user's flow of creative ideas and familiar design processes and supportive tools. Designers as a group are often early-adopters of new technologies, however, usability aspects of software are of utmost importance.

Contribution of this research

The created technology helped designers in improving sense of *awareness and presence* while working with design content. The semantic tool is designed in a way that in principal, the designer is always informed about related and relevant material to that may already be stored in the designer's local repository, for example working with design brief or sketching the concept of new product, as visualised in Figure 11.

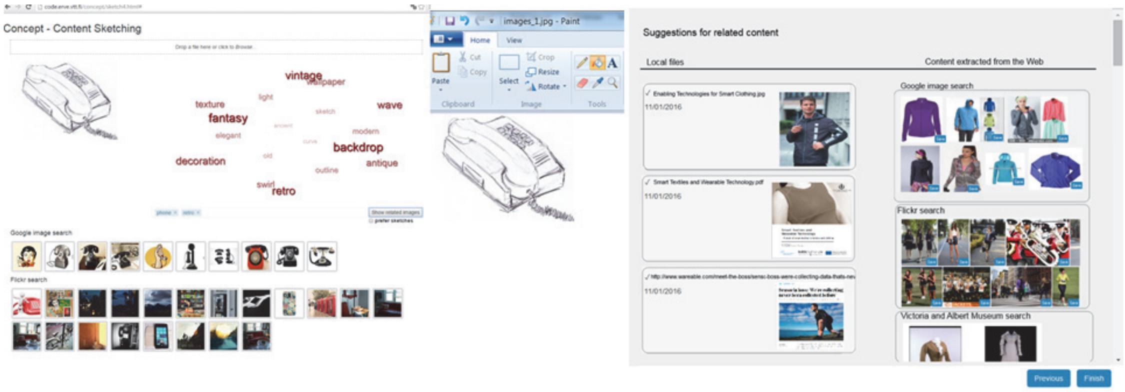

FIGURE 11 Relevant content suggested based on the information extracted from designs

The technical implementation of the tool is relied on several components such as semantic content annotation, content search and recommendation. The intelligence of the proposed tool is supported by domain-specific knowledge model – expendable design ontology. The developed design ontology aims at supporting the designer's creative abilities and overall process of conceptual design whilst managing content and enabling the dynamic personalised indexing and search of design content. To support the awareness and presence over the relevant design content, the design ontology is defined as an extendable set of core classes: at the centre of the top level, nodes of the ontology are *Product*, *Person*, and *Content*, as well as *DesignProject* and *DesignTeam* classes (see Figure 12). The semantic network of five classes interconnected with a set of object properties is defined to represent both personal and collaborative aspects of the designers' work, connecting the user as both designer and end user, product under design, and the related design content associated with the product.

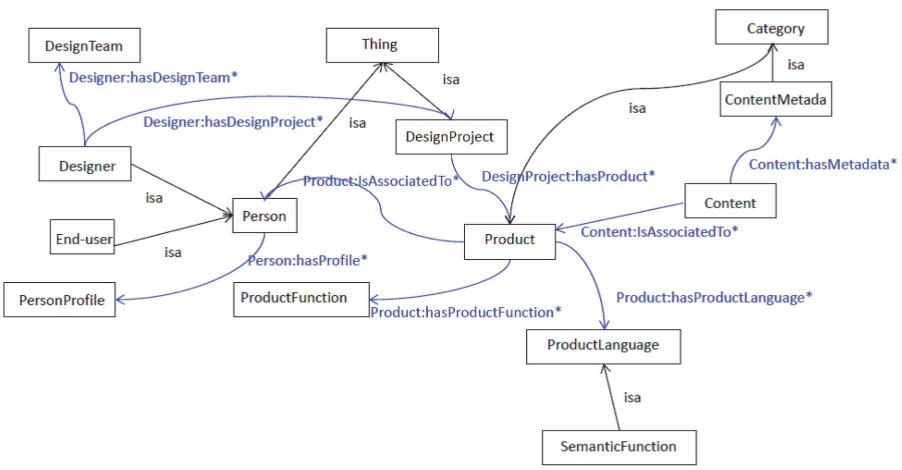

FIGURE 12 The top-level classes of design ontology

The model of product class in the ontology uses the Offenbach theory of product language (Steffen, 2007) and is defined to attain a common vision through the set of ontological concepts, allowing the product to be described from different points of view, such as the domain of the product being designed (e.g., web, fashion, kitchen-ware or consumer electronics), deployment technology, ergonomic, economic, and ecological properties, and emotional response and associations created while interacting with product (e.g., historical aspects, style, cold, warm, aggressive). The reuse of the pre-defined domain specific ontology is often restricted by its static nature. Thus, functions are provided to enable the designer to customise i.e. add, rename or remove ontological concepts as a part of the content annotation process (i.e. crowdsourcing of model). The design resources can be further filtered and organised by the designer according to the concepts of the design ontology.

The evaluation of the developed prototype was supported by constructing an evaluation scenario related to the conceptualization of a new 'smart sport jacket' as illustrated in Figure 11. Each participant was asked to perform various tasks, such as working with the design brief and other material, sketching and testing the design ontology, while inspecting the suggested content metadata. Moreover, test-users were encouraged to experiment with the tool using their own material (documents, images, web-pages, etc.). Furthermore, qualitative feedback related to performance issues experienced, desired functionalities and preferences regarding the maintenance of knowledge models was queried and recorded. The assessment questions were built around three fundamental issues contributing to the user experience: fluency of use, experience and 'liking', and the position of technology in human action.

The testing group containing 12 participants was constructed as a mix of users with diverse expertise in the areas of product design, UI/UX experts and business. Overall, the quantitative evaluation indicated that the respondents perceived the functionality of the tool as useful and inspiring. Moreover, most of the respondents indicated that they would like to have tools as part of their design environment suite. The respondents also proposed some additional features that could improve transparency and the understandability of the toolset. For example, the approach may better indicate how documents are related to each other and enable adding free-text comments and notes to content items.

To conclude, considering that the target user group requires a seamless and intuitively familiar technology, the challenge for the developers while enabling the awareness and feeling of presence and comprehension of contents, is to create a "knowledge management interface" that can be seamlessly integrated into a set of familiar design tools, and which is automated as much as possible while yet providing the perceived feeling of technology control. The user may add or delete metadata or select one image over another, and the software is able to use this information to prioritise presentation of new information to the user as effectively as possible. *The focus* is on the *content generated and perceived feeling of awareness* rather than the 'interface' in its traditional meaning. As far as the user is concerned, the system is performing magic by presenting new content based on the initial design brief or sketches. As the designer interacts with the software, it should become ‘smarter’, returning more relevant content as it learns the user’s “preferences”.

4 THEORETICAL FRAMEWORK

The objective of this chapter is to summarise the experimental knowledge acquired from domain-specific studies discussed previously. The aim is to lay out the dimensions of awareness in terms that are useful for designers. To this end, first, the domain specific studies with objective to make the aspects, which contribute to the perceived feeling of awareness are analysed. In the next step, the identified aspects are grouped to the bigger assembles of features towards the theoretical abstract framework, which the designer can use in order to support awareness in products design.

The created framework is supported by the domain knowledge gained during the design, development and evaluation of prototypes presented in the previous chapter and also by the related existing studies, which are further discussed later in this chapter. The framework is intended as a high-level guide rather than design rules and instructions since many details needed for the particular implementation are determined by the context of the particular technological system and mostly important by the user of the system. The framework is served as an *ontology of design questions and vocabularies* - for thinking about awareness in the product design.

4.1 The analysis of domain-specific studies

Each domain study discussed in Chapter 3 has been analysed with the aim to explicitate the knowledge elements and aspects that support awareness and thus lead to the feeling of perceived confidence, autonomy or possibly motivate to perform some action. These elements differ from the functional features of the system have being developed, such as for example, the functional purpose of the cooking guide application (Paper II) was to provide user with instructions and recipes to prepare some dishes. However, the non-functional features of the cooking guide (where awareness belongs) are concerned with such aspects as providing its user with additional knowledge about the usage of utensils required to make a particular dish and the specifics of cooking processes as well as to motivate users in cooking at home for themselves, family and friends. The acquisition of respective aspects has been facilitated by numerous workshops and discussion with users as well as by using afterwards evaluation of prototypes, during domain specific studies. The results of the analysis are collected in Table 1.

TABLE 1 The analysis of domain-specific studies

Domain specific study	**Functional aspects of the system**	**Non-functional aspects that support awareness**
Smart home	Running home devices and services in an automatic context-aware way	• Enabling to connect real and digital representation of own house – all in one view, providing insights when necessary • Helping with finding house-related information easier (services, data, devices, etc.) • Enabling to see if everything works as supposed on the background • Providing understand about how smart appliances work • Enabling user with tool to master own home, being smart maintainer • Providing support for home data visualization with aim at liking effect and creating positive emotions
Cooking guide	Providing with guiding instructions and cooking steps, advising ingredients and new recipes	• Providing with understanding on the state of the cooking process - where am I in the process • Giving ability to skip some cooking steps, explaining why product works in this particular way • Providing with understand about the purpose of various cooking utensils • Enabling learning of new recipes, new ways of cooking and cooking trends • Supporting with seeing on how/what others are cooking • Guiding and educating towards motivation to eat other fancier/healthier food through • Providing a suitable recipes to encourage cooking at home and buying other related/complementing products (e.g., more smart utensils) through bringing relevant insights
Product assembly	Automating some work processes with assistance of smart products as well as helping in collection of information around the assembly floor	• Enabling seeing roles, tasks, schedules (manager) • Supporting representation of work processes better towards further analysis/processes optimization (manager) • Providing "big picture", "progress" of assembly floor (manager) • Providing support for quicker adjustment of tasks, roles (manager) • Providing with information on the status of equipment (manager) • Supporting understand the content of the task (operator) • Enabling seeing what others are doing (operator)

Medical emergency response	Managing heterogeneous information about incident, providing interoperability & decisions support	• Enabling information visibility and transparency for responders involved • Providing as much correct information as possible • Showing progress of emergency response activities (e.g., patient status) • Providing awareness about own role as responder such as e.g., triage, transport • Providing with task-related instructions if needed, with more professional info e.g., about hazard type • Giving information about decisions to be made and when • Providing with information about previous similar situations, decisions made • Providing with awareness that other roles "are taken" • Supporting ability to report own achievement • Supporting propagation of decisions and their representation by the system • Explaining suggestions made by system
Product conceptualization	Managing design content (save, load, search)	Helping designer with/ Providing support for: • Being aware about related design content • Bringing domain knowledge • Finding some unexpected contents, "surprise" effect thus getting inspired • Interactive annotation functionality connected to content search thus supporting motivation to produce more design content / to obtain more related suggestions • Smooth/seamless interactive content search and presentation thus supporting in getting into a "flow state", "I can do this" Being "seamlessly" better connected to other designers by displaying/linking designer to other existing designs

It can be seen from Table 1 that some aspects such as understanding of own state in the process when interacting with product or awareness about own role (and roles of other people) in the decision making and the ability to report own achievements are related to the knowledge about users themselves. The other aspects such as, for example, information related to the functionality of product and how users can control and interact with it are concerned with product in use. In addition, many aspects and features of product aim at supporting user with background information related to the domain of product usage. The examples of such features are learning new aspects of cooking and modern utensils in a cooking guide related study or acquiring necessary professional information required to better perform emergency response tasks.

Furthermore, many product aspects presented in Table 1 are directly aiming at awareness towards the creation of a positive emotional outcome for product user. The examples of such emotional outcomes are getting inspired and motivated to sketch more (study on the product conceptualization) or increasing personal confidence when making decisions (studies on the product conceptualization case and emergency response).

Accordingly, the identified features are further grouped into bigger assembles (as visualised in Figure 13):

- Self-Awareness:
  - o Understanding where am I in the process when interacting with product;
  - o Experiencing progress, transformation;
  - o Understanding own abilities, reflecting ourselves against others.
- Product Awareness:
  - o Understanding how product works;
  - o Understanding why product works in a certain way;
  - o Having a perceive sense of control;
  - o Being able to master technological environment.
- Domain Awareness:
  - o Learning new things when interacting with product;
  - o Improving and gaining new skills;
  - o Widening experience.

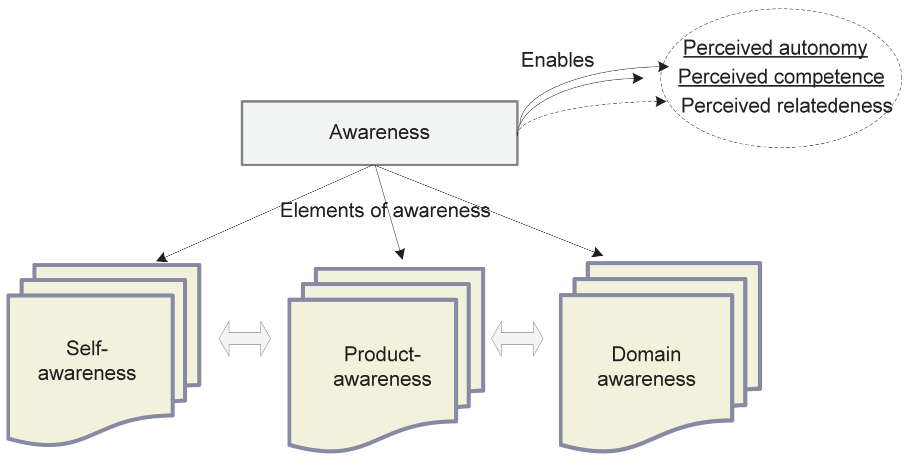

FIGURE 13 Elements of Awareness

Addressed by design, various elements of awareness may contribute to the feeling of perceived autonomy or competence. Consequently, this may lead to the several positive consequences and mental states such as occurring state of curiosity or flow experience or being motivated to use product more and to recommend product to others. In fact, research studies indicate, that flow experience is frequent while performing a variety of tasks in use of information technology. It was pointed that better usability can be achieved by designing interfaces that induce flow experiences in design (Pilke, 2004; Pace, 2004). According to (Csikszentmihalyi, 1996; Seligman & Csikszentmihalyi, 2000; Snyder & Lopez, 2007), the optimal experience or flow is a mental state of extremely rewarding concentration. Such features as clear goals, immediate feedback, sense of control and merging of action and awareness as well as of course the functional balance between challenges and skills have a great influence on the occurring of this optimal experience.

Next, we aim at the explaining the identified types of awareness into psychological terms. These are supported by cognitive science and existing explanatory frameworks on mental contents discussed earlier (Simon, 1955; Newell & Simon, 1972; Saariluoma, 1990, 1997, 2004). The objective is to provide with understanding how and why the mental content such as thoughts, emotions and intentions are formed and can be manipulated with a support of awareness. Schema and related mental processes (assimilation, apperception, and self-assessment) are an important constructs which help to understand and explore the awareness (Piaget, 1926, 1952; Neisser, 1976). In Section 4.2, awareness is approached from human's internal mental content point of view. In Section 4.3, awareness is considered from external perspective of human behaviour.

4.2 Awareness – internal view

4.2.1 Supporting Self-awareness

> ”Self-awareness is a rich and complicated subject and is arguably the most fundamental issue in psychology, from both a developmental and an evolutionary perspective” (Rochat, 2003).

During the recent years, the amount of data stored by computer systems has increased dramatically. Ranging from exercise and home utilities usage logs to archives of our interactions with others on social media, data is recorded, captured, and stored in various automatic and manual ways and forms. Consequently, the enormous potential for usage of this data has generated the vast of visual research to explore the enabling techniques and technology that can support people to better understand data relevant to their personal lives, interests, and needs. The research on Visualization and Visual analytics, which spans across different application domains from applied scientific visualization and computer gaming over ubiquitous computing and intelligent environments to social media, has delivered concepts and experimental insights that can be taken into account here. The excellent research literature overview in this filed with focus put on visual analytics applied in the personal context (not required professional training or analyst's perspective, so in principle fits also with some use cases in work context) is given by (Huang et al., 2015). The publication covers a variety of developed and evaluated application prototypes that address most aspects of daily life, e.g., residential energy consumption, fitness, personal health, social networks, politics, residential environment, life logging, personal finance, and recycling. This study has reported interesting clusters that were observed by exploring existing research in interactive visualization.

This *literature review* complements our domain specific studies. In addition, it is served here as a source of additional information to further understand what motivates people to explore data and how. The identified three clusters and dimensions that characterized each cluster are presented in the following.

Curiosity satisfaction. The design goal for the tools in this cluster is to support users to understand something about themselves rather than to support taking specific actions or making changes or decisions. Data exploration is driven by experience and personal knowledge of users. Applications in this category have self-centred focus helping to explore, "my data" such as documents, finance or visited places (e.g., Barata, Nicolau & Goncalves, 2012). The example of applications in this category may enable users to explore their music listening history or history of cooking as discussed in the study reported in Paper II. Technological artefacts and tools here usually require high attentional demand from the user and support a high level of explorability. However, insights obtained from using the tools are typically not very actionable (i.e. the outcome might help me to better understand and assess myself, but does not tell me how to change my life).

Awareness for action. Applications in this cluster aim at providing on-going awareness with respect to for example personal behaviours such as quality of monitored sleep or energy and water consumption with an aim to encourage for some behaviour changes (Costanza, Ramchurn, & Jennings, 2012). Applications may aim also at revealing some insights of residential environment as studied also in Paper I. As for the data representation means, some applications use decorative ambient displays to make the technology less intrusive and better fit in the home environment (Froehlich, 2012), others ran on a personal computer, enabling close exploration and organization of family data to track progress (Kientz, Arriaga, & Abowd 2009) or TV system to enable people to view real-time energy use at home (Schwartz et al., 2013). Designs reported here, support continuous awareness with low attentional demand, and enable looking up data with a quick glance thus aiming at low explorability, however, achieving actionable insight.

Reflective awareness. Applications in this cluster indicate people's interest in data about their surrounding living and working community. In our studies on product design (Paper IV), reflective awareness was identified as crucial element to support designer during the exploration activities and when working on the initial product concept toward the support for confidence and motivation to use the tool. In the literature review, these applications are mostly used for reflection purposes (e.g., exploring social patterns on campus (Shen & Ma, 2008), investigating how topics of tweets evolve over time (Dork et al., 2010), or comparing the vote rank of candidates in an election (Wood et al., 2011). In some examples, they are also used to encourage behaviours valued within the community such as in (Hazlewood, Stolterman, & Connelly 2011) ambient displays in a department lobby to incite energy conservation in the building and encourage physical activity (using the stairs rather than the elevator) are deployed. Tools in this cluster mostly employ many traditional visualization techniques to facilitate deep analysis, usually requiring high attentional demand.

What motivates people to monitor self-related data?

Theorising and explaining the experimental studies, it is useful to look on the relevant psychological concept to progress with the awareness design framework. Several concepts such as *self-concept*, *self-assessment* and *self-efficacy* are important to consider when explicating self-awareness in psychological terms towards its implications to the technological research.

The self-awareness is looked here from two perspectives. One perspective view concerns with knowledge about "self". Other view is more "situational" in a sense and it relates human to his/her state in some process, activity or task when interacting with technological system. Both aspects are further discussed in the following and we start with a former one.

"Self" and "Situational" aspects of self-awareness

As discussed in Section 2.2, self-concept is a complex knowledge structure, which embodies a variety of different cognitive aspects and beliefs of the self (own abilities, values, goals, social image as well as physical appearance), known as self-schemas. Self-concept interacts with self-esteem, self-knowledge, and the social self to form the self as whole. Due to its complexity, it has a particular influence on our thoughts, emotions (i.e. mental content), academic achievements, behaviour and general levels of happiness, anxiety, social integration and general life satisfaction (Sadhwani, 2012; Deepty & Geeta, 2015; Suárez-Álvarez, Fernández-Alonso, & Muñiz, 2014).

Then self-awareness refers to the extent to which we are consciously focusing our attention on our own self-concept, feelings, motives, and desires. Our current concerns and interests are somehow dependent on the accessibility of different self-schemas. When the knowledge contained in the self-schema becomes more accessible, it also becomes more likely to be used in information processing and to influence our behaviour (Stangor, Jhangiani, & Tarry, 2014).

The important for our research in particular is that self-concept uses the process of *self-assessment (or self-evaluation)* to assess the aspects that represented in human schemas. The psychological research suggested that self-assessment motive prompts people to seek information to confirm their self-concepts or to enhance their certainty of their own self-knowledge and beliefs *(Sedikides, 1993; Sedikides & Strube, 1997)*. Subsequently the information related to self-schema/oneself is processed more efficiently and better remembered. Also one pay attention more actively to information that is relevant to self-schema while information which is in contradictory with own self-schema tends to be resisted.

It is then logical to assume that technology should support the accessibility of self-schema as well as the process of self-assessment towards being perceived more useful. The cluster of applications discussed earlier in this chapter and some of functionalities reported by domain studies, Chapter 3, aim at satisfying perceived inner need for self-assessment.

The process of self-assessment is an important part of self-efficiency evaluation. According Albert Bandure's theory of self-efficiency, it's "the belief in one's capabilities to organize and execute the courses of action required to manage prospective situations" (Bandura, 1977, 1997). Thus, self-efficiency is built on various levels of self-awareness supported by the outcome of self-evaluation. The resulted *experience of mastery* supported by self-awareness is the most important factor affecting a perceived self-efficiency and motivation to accomplish a particular task and thus should be supported by technology by the design. There are many studies exist, in particular applied to the educational context, confirming that high self-efficiency can affect motivation in a positive way (Skaalvik, Federici, & Klassen 2015; Lackey, 2013; Juutinen & Saariluoma, 2007).

Technological self-efficacy (TSE) represents a specific application of a more general and complex construct of self-efficacy. Technological self-efficacy is related to belief to the ability to manage the technology. There are many studies available which discuss the influence of TSE on the acceptance of technology in various domains such as for example learning and teaching (Heaperman & Sudweeks, 2001; Tsai et al., 2011; Aesaert & Braak, 2014; Chen, 2014; Lemon & Garvis, 2016), job performance (McDonald & Siegall, 1992; Raghuram, Wiesenfeld, & Garud 2013), health context (Rahman et al., 2016) and the usage of computer and Internet services (Durndell & Haag, 2002; Ma & Liu, 2007; Gangadharbatla, 2008; Lee, 2009). Older people has also extensively studied in TSE in relation with the acceptance of technology (Reed, Doty, & May, 2005; Posthuma & Campion, 2009). Although more complex theoretical development and empirical examination concerned with how technology can support (i.e. boost) general self-efficacy have not been yet far addressed and this is a subject of the following discussion which lead us to the "situational" aspect of awareness.

Experimental studies that are reported in Papers II, III and IV and literature review discussed earlier confirmed our hypothesis about importance of visual representation of various states and workflow, when supporting interaction of users with technological system. We call it "situational" awareness here. Such visualizations may effectively underpin a *perceived feeling of progress* and *experience of mastery*, when accomplishing a particular task.

Processes and workflows appear to be an important element of our life. Some individual everyday actions such as waking up, having breakfast, dressing and so on are part of larger workflow or a collection of actions towards the fulfilment of certain goal. Keeping "To Do List" is another example of scripting the list of actions and goals in form of processes and workflows we like to do and accomplish. Further, the research on goal pursuit (Gollwitzer, & Brandstatter, 1997; Bonezzi, Brendl, & De Angelis, 2011; Amir & Ariely, 2008) and well-being (Wiese, 2007) reveals an important dependence between progress on our goals, motivation and our reports of happiness and life satisfaction (generally referred to as "subjective well-being"). Progress on goals makes people feel more satisfied with life. We want to get better at doing things. It is why learning a language or an instrument can be so frustrating at first. If we feels like we are is not getting anywhere, our interest flags and we may even give up. A sense of progress, not just with task, but in our capabilities, contributes to our inner motives. State awareness further contributes positively to self-efficacy and consequently, influential to beliefs and intentions. All actions have goals, or, when mentally represented, the goal is expressed as *intention* and *interest* (Brentano, 1874/1973). According the theory of action in philosophy, the desire and belief jointly cause the action (Davidson, 1963). Further, psychological research suggests that there is a link between *desire*, *beliefs* and *intention* (Astington, 1993; Perner, 1991; Bertram & Joshua, 1997). Mental mechanisms including intention, explain behaviour of individuals who have desires and who attempt to achieve particular goals that are directed by mental contents such as beliefs. Thus, an intentional action is a function to accomplish a desired goal and is based on the belief that such action will satisfy a desire.

According the script theory (Tomkins & Bertram, 1992; Schank, 1990; Wiederman, 2005), the human behaviour can be represented by patterns called scripts. In the subsequent literature, scripts are used to describe virtually any frequently recurring social situation that make up much of our lives. Script can be understood as a representation of stereotyped sequence of events in a particular context such as ordering food in the restaurant discussed earlier, shopping or attending social events. Script can be seen as a process-oriented concept that helps to deal with human knowledge and understanding.

We do not have such script to support our interaction with new product, could it be then the reason of perceived difficulty we experience, when interacting with technological systems at first time. We strongly believe that to be better acceptable, new technological systems need taking care about this by providing its user with certain awareness about interaction workflow and aspects related to the state of the user in respect of where he/or she is positioned in the process of interaction with product.

In computer science, self-awareness in a relation to states-, processes-, and task-awareness were studied by different sometimes-overlapping research communities. Process awareness has been mainly investigated from the system point of view and falls into the field of Process-Aware Information System (PAIS) (Dumas, Aalst, & Hofstede, 2005). Subsequently, there is a considerable research work has appeared in the field to provide the support for modelling of processes and workflows, including modelling languages, business process visualization and the development of process-oriented applications, however, there is a little effort put on understanding the human ”place” in these models. Recently the focus of PAIS has shifted more on process participants towards so called A Human-Centric Process-Aware Information Systems (HC-PAIS) design (Kabicher-Fuchs, 2012), while still with focus put on work environments and on in better incorporating of the required human knowledge, skills, competencies, experience, and decisions into work processes. Nevertheless, the ultimate goal of a HC-PAIS should be happiness, motivation, and satisfaction and consequently, better performance of humans working with the HC-PAIS and technology acceptance. There is also a vast research on the analysis of computer-human interactions and behavioural patterns during computer activities exist, however, the existing work has focused primarily on developing better user models and on improving understanding of user actions towards the more personalised service delivery (adaptation).

Instead, here we sought for the theoretical background that can help providing users with better self- and state-awareness in the context of interaction with technology, which consequently, can positively influence core self-efficacy. When designing new product, respective technological artefacts (such as progress monitoring, interactive workflows and state visualization, instructive feedback, reflective/comparative data analytics) can be infused into the functional operation of product to support the aforementioned aspects. The attempt to structure our discussion on the complexity of "Self" and "Situational" aspects of self-awareness is presented in Figure 14. Such concepts as self-efficiency, self-evaluation and self-concept are important to consider when implementing self-awareness in product design. Further, when supporting human action, awareness about the state of interaction with a product in form of progress and level of completeness are essential to empower personal self-efficiency.

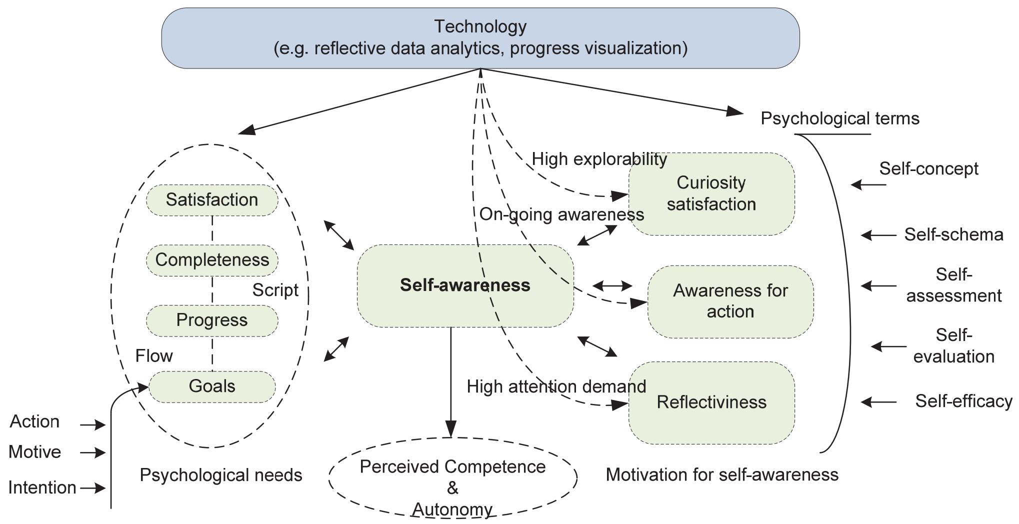

FIGURE 14 Towards the structuring of self-awareness

4.2.2 Supporting product awareness – explain me

The explanation is a mean and supporting construct to provide us with understanding about self, the product and the domain, where product supports us. Explanations are more than a human preoccupation – they are central to our sense of understanding, and the way in which we exchange beliefs (Lombroso, 2006). In fact, we experience explanations every day, "would you take a cup of tea", "No", "I did take one recently". Accordingly, the nature of explanation has been studied extensively by researchers in philosophy of science, social psychology and cognitive science.

The core of the explanatory process is sounding, coherence, adequate. This means that the *explanandum* (the phenomenon to be explained) and the *explanans* (the explaining phenomenon) should be coherent and adequate. According to Hempel, to achieve this, explanations should be based on science and scientific principles “involving at least one statement of scientific law” (Hempel & Oppenheim, 1948). For example, the expanded coin when heated, can be explained by invoking the law that copper expands when heated and knowing that the coin is made from copper (Hempel, 1965).

In real world situations, however, the explanations are less scientific and they are often designed to satisfy the questioner. The explanation enables us to understand why the phenomenon occurred. A system can be called, as an ‘understanding system’ as soon as it is able to explain own actions to the human user but also to itself (Schank, 1986a). The spectrum of understanding may range from making sense over cognitive understanding to complete empathy. With current advances in computing intelligence, it can be firmly said that computer understanding is still more at the stage of ‘sense making’. According Schank, three classes of things can be explained: *the physical world, the social world, and individual patterns of behaviour* (Schank, 1986b). The three classes together with the abovementioned spectrum of understanding can help designing concepts that reasonably can be explained by a computer. The easiest type of explanations are scientific explanations. However, to trust the system, the human user is also interested in other types of explanations to decide about how much trust can be given to a system. The obvious approach to increasing the confidence and the belief to a system’s actions and results is to provide explanations of how the results were derived and why certain actions have been made.

According to the *studies in the philosophy of natural language* (Achinstein, 1983), the explanation request can take many forms in number of questions (why, what, where, how, etc.). An explanation is the intention of giving someone the knowledge to understand some phenomena from some frame of reference. Moreover, it is suggested that a very wide variety of statements can serve as explanations. It is also emphasized the value of knowing the recipient well and it is suggested that to form efficient explanations, accurate user models may be necessary.

Further, the theory of explanations developed by (Thagard, 1989) has introduced the notion of acceptability and three important criteria for selecting the best explanation: consilience (favouring explanatory breadth), simplicity (favouring explanations with few propositions), and analogy (favouring explanations based on analogies).

Looking more on the cognitive studies in this area, already Aristotle identified four modes of explanation that bring different aspects of an answer to a why-question: the efficient, final, formal and material one, see Table 2 (Preus, 2015; Reece, 2018). The cognitive research has suggested that final and formal explanations correspond to psychologically real modes of understanding. For example, children are prompt in their acceptance of final causes: they claim pens are for writing, but also that mountains are for climbing. By contrast, adults accept final cause explanations selectively (Kelemen & DiYanni, 2005). The clauses of Aristotle have found some resonance in the philosophical studies of Martin Heidegger, one of the main contributors to the Phemenology. In his work, “The question concerning technology", Heidegger discusses the essence of technology. He also states and narrows that technology as a means to a human end, so that this conception can therefore be called "the instrumental and anthropological definition of technology (end, final cause of human activity)" (Heidegger, 1977).

TABLE 2 The Aristotle's models of explanations

Cause or model of explanation	Description	Example
Material	The substance of which something is constructed.	The bookshelf is solid because it is made from wood. Wood is a material cause of chair.
Formal	The form or property that make something what it is.	Bookshelf does not collapse because it has four legs. Legs are a formal cause of chair.
Final	The function or a goal, a sake of which thing is done.	Bookshelf has shelfs because it is made to shelf the books. Having shelfs is a formal cause of bookshelf.
Efficient	The proximal mechanism or agent of a change.	An efficient cause of a bookshelf is a wood maker.

In *computer science and engineering*, the explanation interfaces have been a subject of intensive studies in Expert Systems and later in Case Based Reasoning research. The studies of (Sørmo, Cassens, & Aamodt, 2005) and Roth-Berghofer (Roth-Berghofer, 2004) are stood out towards the support of this research thesis, in particular to address the quality of explanation artefacts. Sørmo presents a framework for explanations in intelligent system, which identifies five goals that explanations can satisfy from the perspective of a human user: *transparency*, *justification*, *relevance*, *conceptualization* and *learning*. The transparency is concerned with the system's ability to explain how an answer was found. The justification deals with the ability to explain why the answer is good. The relevance is addressing the importance of a question asked. For example in conversational systems, the user may wish to know why a question asked by the system is relevant to the task at hand. The conceptualization is the goal that handles the meaning of terms i.e. vocabularies used by the system towards their clarification. The learning goal aims at transferring the knowledge contents and competence of the system to the user. Learning interfaces are further discussed next in Section 4.2.3.

Studies by Roth-Berghofer has identified number of explanation types required by a case-based reasoning system (Roth-Berghofer, 2004), which partly overlap with goals discussed above. Conceptual explanations answer questions regarding the semantics of concepts. Why-explanations describe causes or justifications. How-explanations depict causal chains for an event. Such explanations can be formed by systems that have an elaborate model of the word, application context, i.e. application *domain model, which is rich in classes and attrib-*

utes (Roth-Berghofer, 2004). Hence, the vocabulary knowledge container with its knowledge base can provide most of the knowledge for different kind of explanations. For example, in all studies reported in Chapter 3 respective domain models for smart home, aircraft assembly environment, designers' working context, etc., have been developed to design and develop various aspects of awareness.

According (Swartout & Moore, 1993), the aspects of good explanation in a knowledge-based system which are important to address are related to *fidelity* and *understandability*. The former means that explanation must be an accurate representation of what the system does. Therefore, the explanations must be based on the same knowledge that the system uses for reasoning. The latter suggests that generated explanations must be understandable, i.e. conceptually as well as regarding its content. The explanations also should be *innovative* with respect to the knowledge of the user. They must be also relevant with respect to the goals and intentions of the users at an appropriate level of abstraction. Moreover, the system should be able to explain its knowledge from different perspectives and should sound *'natural'* and adhere to linguistic principles and constraints.

Still although explanations have been discussed in the scientific literature with a support of some of experimental studies, much less is studied about the content and role of explanations in real-world reasoning. For example, what make people to seek for explanations or to generate ones and how the technology can anticipate and support the need for explanation? User psychology and a number of important concepts such as schema, script, plan, etc., discussed earlier can help here. One motive for the search for the explanations is that one could prepare oneself for similar future situation. According to Neisser's perception-action cycle model discussed earlier, visual perception is a continuous activity of looking at things, which involves the anticipation of information. This process depends on internal structures, -schemas, that function as anticipations and as plans (Neisser, 1978). The explanation is a supporting component and enabler of the accommodation process introduced by Piaget and discussed in Section 2.2. We need explanations to support mental processes of assimilation and adjustment of our mental schemas in particular in a situation, where action or reasoning of system is far from the schema we have or not immediately obvious. For this reason the opening and analysis of individual schemas is a good approach to the design of the explanations of the system. One approach taken when developing cooking guide application (Paper II) was to introduce the learning means to follow the reaction of recipients on the actions made by technology. For example if some explanation regarding cooking processes is noticed being cancelled, next time system was able to adjust the explanation accordingly.

Furthermore, real-world applications, which involve intelligent products resided in a physical environment, set the requirements to the *situated* and *reflective* explanations. They link information and knowledge to situated context thus answering such questions as "where am I in the process when interacting with technology", "where is the device which gives a particular information" -

Physical World or reflective explanations, which provide more insight on subjective aspects of the human user and his/her environment, for example, how do I perform compare to others - Social World. These elements are related to the concept of self-awareness as have been discussed in details in Section 4.2.1.

Moreover, the purpose of the system plays an important role in defying of respective elements that influence system acceptance. When interacting with work- and task-oriented systems, the perceived usefulness is more important (such as in medical emergency management). In contrast when interacting with hedonic systems that are aimed at fun and pleasure (as cooking guide mostly does) the perceived enjoyment is more desirable in achieving user acceptance (Cramer et al., 2008). Synthesizing the existing studies and combining them with the experimental studies discussed in Chapter 3, allow us to propose the ontology of explanation interfaces (see Figure 15), which aims at helping the designers to think about "what", "why" and "how" should be explained by technological system.

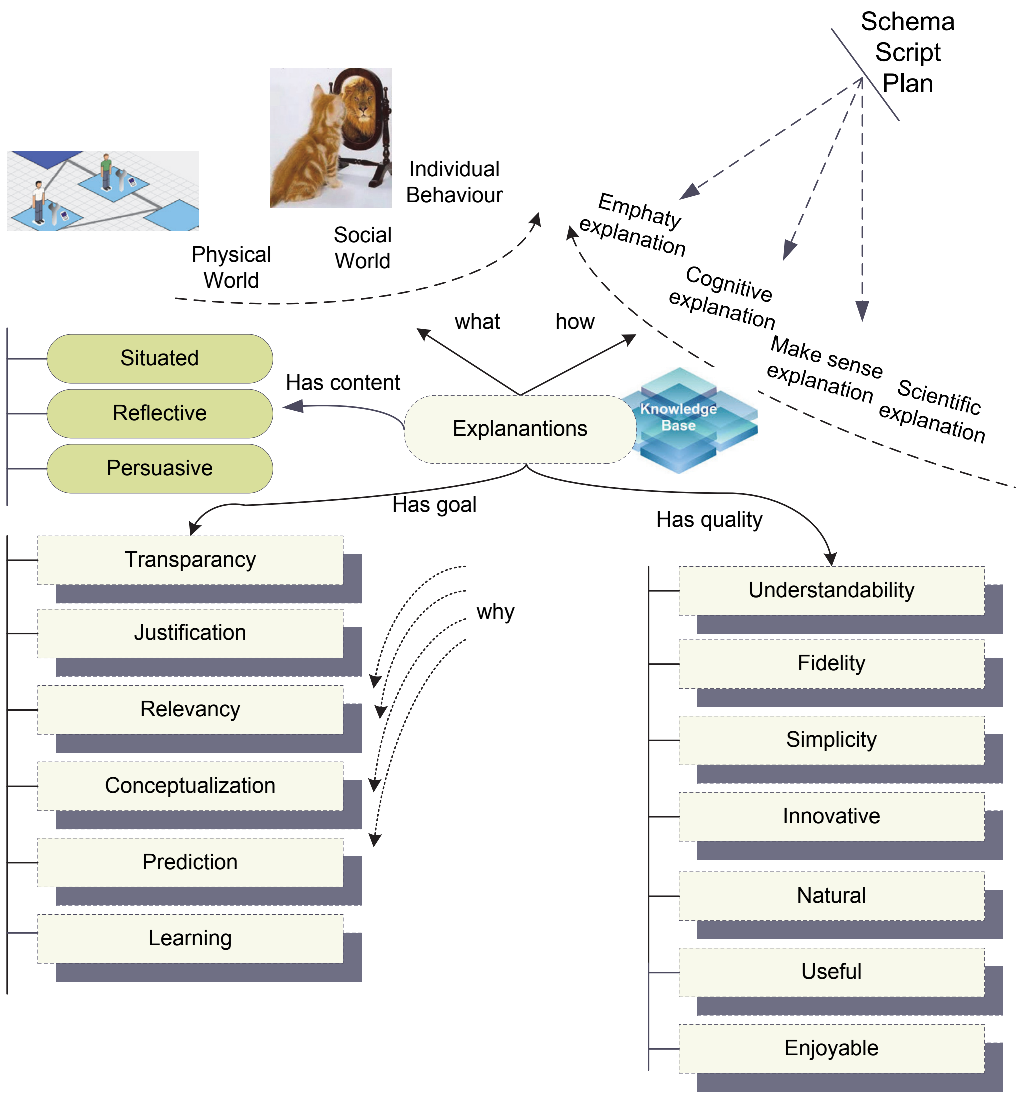

FIGURE 15 The ontology of explanation interfaces

Last but not least, visualization is empowering tool to enhance consciousness, self-awareness and general understanding of product and domain, when designing HTI. Effective visualization makes complex data more accessible, understandable and usable for the user. Thus, the primary goal of data visualization is to transform data, information and knowledge into a visual form exploiting people's natural strengths in rapid visual pattern recognition (Gershon & Eick, 1998). "Like language, visual communications abstract and schematize to convey meanings. The visual expressions of these meanings (e.g., individual, category, order, relation, correspondence, continuum, hierarchy) have analogy in language, gesture, and especially in the patterns that are created when people design the world around them" (Tversky, 2011).

In recent years, the rapid development of computer game graphics has had a huge influence on visualization. The computer games industry has come up with new approaches presenting data on computer screens in an illustrative and impressive way and succeeded in effectively exploiting different kinds of visualization techniques. The rapid financial growth of the computer games market has made it the driving force in the development of consumer graphics, applications and hardware. It is succeeded in effectively exploiting different kinds of visualization techniques (isometric perspectives, 2D/3D views, spatial relations between objects, etc.). Nowadays many of the approaches implemented for educational or scientific purposes are inspired by computer games. Grounded to the psychology, game industry also delivered some interesting concepts, game-like design patterns and visual aids to address the aspects of motivation such as setting and monitoring of goals, progress visibility and completeness. Completion feels intrinsically rewarding. This observation is also supported by Gestalt low of Closure, which aims at explaining the aspects of visual perception of humans. If properly addressed by design, this powerful motivator can help designers in creating of engaging user experience while mastering applications and services.

Which visualization type should be used depends on the problem domain. Different styles are effective for different situations. For example, the visualization of intelligent environment such as home or factory floor requires that contextual information and spatial relationships be presented effectively in the visualization. In addition, the visualization should be realistic, as realism supports the expectation of accuracy and reliability in the representation, especially when considering computer graphics that aims at simulating of real environments (Luymes, 2000). Therefore, for example the traditional graph visualization algorithms that are mainly focused on representing the abstract relationships between objects are not considered the best possible solutions for this particular problem domain of HTI and smart products design.

Explanations are accompanied by a sense of understanding and satisfaction (Gopnik, 2000; Dawes, 1999; Ahn, Novick, & Kin, 2003) and thus they should be employed by design. Moreover it is recognised that explanation facilitates learning in a variety of contexts, including science instruction (Chi, 1994), mathematical problem-solving (Rittle-Johnson, 2006) and strategic game-playing (Crowley & Siegler, 1999). The design of leaning features in explanations is discussed in the following section.

4.2.3 Supporting domain awareness – product user as a learner

Learning is an important attribute to fulfil our inner psychological need of perceived competence. Furthermore, there is a link between learning, curiosity and motivation. Experimental studies revealed that curiosity prepares our brains for learning. It was found that, once the subjects' curiosity is invoked by for example, right question, other related information is better learned. In addition it appeared that when the participants' curiosity had been sparked, there was not only increased activity in the hippocampus, which is the region of the brain involved in the creation of memories, but also in the brain circuit that is related to such emotional content as reward and pleasure (Gruber, Gelman, & Ranganath 2014).

There is a vast of research that is concerned of learning theories and technology enhanced learning (Westera, 2010). Furthermore, the importance of prior educating of user to use the technology in order to assimilate it quicker is well recognised. However, in this research we are looking rather on the design of products to support user in *learning as a "background effect"*, thus learning here is a secondary function of product towards the enabling of domain-awareness. The educating ability of product has its value in work related tasks as was demonstrated for example in the studies related to medical emergency response (Paper IV) as well as in leisure context i.e. cooking guide application (Paper II).

Learning features and, consequently, the domain-awareness induced into products systems may aim at achieving one or more of the following objectives:

- To *provide user with more knowledge* in the domain of the product thus improving perceived competence or satisfying curiosity. For example, in each step of cooking guide application user was provided with additional information on the state of cooking as well as on cooking recipes and related ingredients.
- To *improve user's skills* required to accomplish the particular task. Skills are the more practical application of knowledge. Skills enforce competence and autonomy. In many cases, learning aims at helping with missing resources or tools i.e. "know-how" as in some cases the learning is aimed at fixing a problem that exists preventing person with required knowledge to accomplish particular task. For example in emergency management application the additional instructions and information related to particular type of incident was provided to the first responder to facilitate his/her task and to enhance confidence during the decision making process.
- To *strength confidence* as in some cases, experienced person still may lack of confidence to try to accomplish a particular task. For example in the study related to product design, designers were supported with reflective visualization on the designs made by others. Further, the elements to

support the collaborative content annotation have be researched and prototyped.

- To *motivate* as often people has skills and knowledge to accomplish a task, however, there is a lacks of motivation to do this. For example in smart home studies, the 3D based user interfaces and modelling tools were researched and developed to attract, motivate and encourage individuals (which are often skilful first adopters of technology) in managing own home products and generally in investing to home technology and smart appliances.

The capacity of product to provide educating functions should be taken into product core already at the design phase. This means that for a given product development, it should be necessary to model necessary *Learning Artefacts (LAs)* as well as *Explanation Artefacts (EAs)* as a part of functional model covering both the new knowledge to be linked to the tasks in hands and the knowledge linked for example to the functional attributes related to accomplishing the task. Accordingly, a product can be decomposed into a graph of learning and explanation objects linked to the functional model of the product as sketched in Figure 16. A learning and explanation artefacts can be designed as a collection of adaptable knowledge-transferring recommendation services which can be used to support user in his (her) tasks.

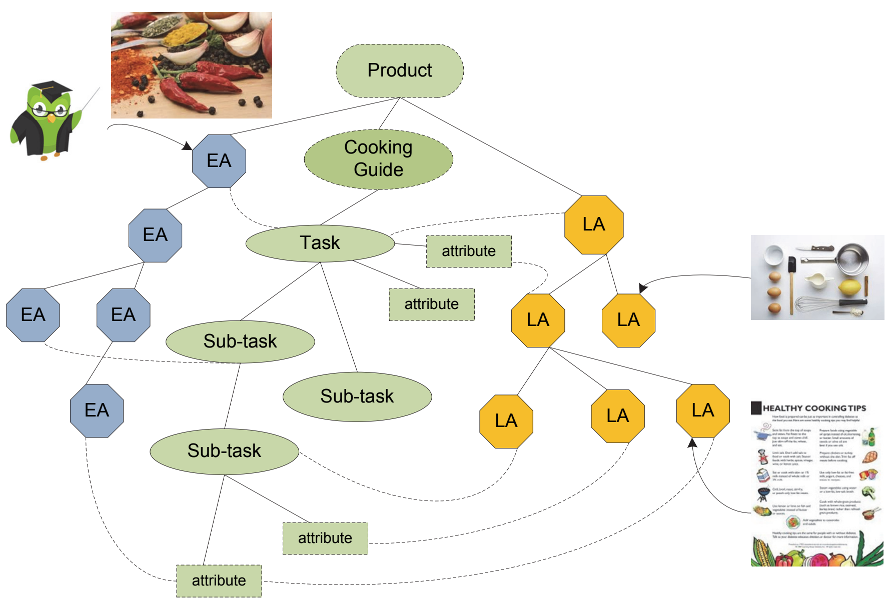

FIGURE 16 The functional model of cooking guide with learning and explanation artefacts

Ideally, the modelled knowledge should be utilised in different contexts. On the other hand, it's difficult to design a knowledge model into the system without having an idea the product will provide the user with. In spite of claims of generality, knowledge-based systems are always designed with tasks in mind (Chandrasekaran, Johnson, & Smith, 1992). Therefore, the relation between tasks, knowledge and related inference mechanisms supporting knowledge transfer should by carefully analysed during design time. As has been demonstrated in Papers II and III, this can be achieved by the use of ontologies, to define the domains in which a smart product is expected to be used, the processes it is designed to support, the attributes or features exposed, what knowledge it requires, user characteristics that influence their interaction with smart products, and how the smart product interacts with its environment and exchanges information with other products and its end users (Sabou & Kantorovitch, 2009).

What (type of) knowledge is required by a smart product systems, is defined during design. The knowledge is actually acquired in two key stages of the product's lifecycle – during development, when domain and process knowledge are generated based on tool functionality and formal specifications, and stored in the system's knowledge base (KB), and post deployment – process, context and user knowledge. This dictates that the design must accommodate re-evaluation and update of the knowledge requirements of a product during use. For example in Smart Kitchen domain (Paper II), the development of Cooking Guide application was supported by a number of application developer-assisting tools such as Smart Products Workflow editor and annotation tools (Webster, Uren, & Ständer, 2010; Zhang, 2012) as well as semantic Smart Product Simulation environment (Niskanen & Kantorovitch, 2011). During the design stage these tools helped to set up an individual profiles of Cooking guide users and to capture the user-centric activities and sub-tasks of cooking guide in form of workflows. Further explanation and learning services have been linked to respective tasks facilitated by the event-action driven design architecture. These are encoded based on the ontology, to allow automatic system adaptation to its users. Information about users and states of workflow/tasks of the system are obtained in the initial stages of use of a product, manually, and at run-time - from physical and virtual sensors.

As there is the need to handle modifications to expected use of cooking guide system, ontology-based reasoning aimed also at supporting substitution of ingredients, or where necessary, whole meals (e.g., to update health plans), such as for example catering for the missing ingredient – 'shallots'. In such cases automated reasoning may be used to identify potential substitutes – here, an equivalent amount of 'red onion' or 'garlic' as another alternative and to explain, making user aware about the proposed change. Supporting this requires knowledge outside the base domain ontology that can be found in other KBs such as for example DBpedia (DBpedia, 2019). Furthermore, necessary explanation can be provided to the user in case of changes acquired in the functionality of the cooking guide system.

The outcome of analysis phase in design of domain-awareness enabled by learning and explanation experience is a crucial for the overall technology design. During this phase the product user and his/her mental content i.e. motives, needs and existing knowledge, skills and interests as well as the learning content required and the supporting resources and tools are identified, as visualised in Figure 17.

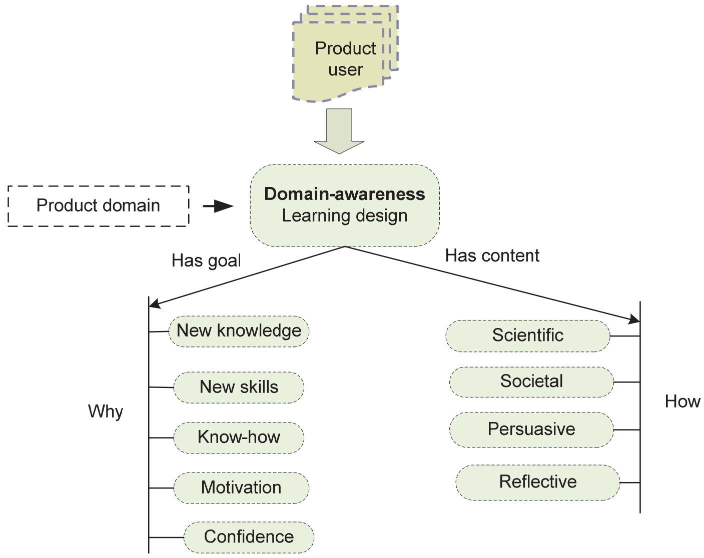

FIGURE 17 Towards the designing of learning interfaces

Consequently, a number of questions needs to be clarified by designer in the analysis phase:

- Who are the learners/product users and what are their characteristics (psychological characteristics, interests, preferences, novice/expert, considering also e.g., expertise reversal effect, etc.)?
- What the domain-awareness aims for? In other words, what is the objective of learning feature i.e. new knowledge, skill or improving motivation or confidence?
- What types of learning content is the most efficient in the particular application/product context and learner state (scientific, societal, domain, persuasive, reflective, etc.)?
- What theory exist to apply thus to maximise the outcome (e.g., learning theory, motivation theory, cognitive psychology, visual analytics, etc.)?
- What are the content delivery options (e.g., video, picture, text, blogs, forums) to make it consistent with the capacity of the user as well as the run-time context of the product under design?

Learning content should be consistent with a self-schema and self-assessment processes of user. Research suggests that self-assessment motive prompts people to look for information to confirm their self-concepts or to enhance their certainty of their own self-knowledge (Swann Pelham, 2002). The aspects related to self-schema and self-verification applied to the technology design are discussed in details in Section 4.2.1. Further, going beyond extrinsic motivation and such supportive constructs as "well done" towards understanding the essence of intrinsic motivation of individual users and curiosity waking up learning-supporting artefacts is important. Many useful information about the user can be understood by product using such simple means as product's set-up questionnaires. Opening the mental content with good question can help shifting learning material accordingly, to invoke curiosity and thus to generate more interest to the new product. In addition, the phenomena of expertise reversal effect should be largely considered when infusing learning artefact into the product functionality. The instructions and guidance that are helpful for less experienced learners are not that effective and even have negative effects when used with more experienced learners. This effect has been investigated since mid-1990s (e.g. Kalyuga, 2007; Kalyuga & Renkl, 2010). In addition, the studies on medical emergency response (Paper IV) revealed that decision makers often rely on long experience and expertise and the preference is made to an extensive availability of information rather than "right information in a right time" as often pointed in the recent research literature. This aspect should be taken into the design by maximising of visibility of available information thus leading to better confidence in decision making supported by awareness. Last but not least, giving learner the control on learning tools provides with perceived feeling of autonomy and thus essential in design. For example, in cooking guide application (Paper II), educating features of application could be easily tuned off by recipients or modified according to environmental or social context (home/outdoor, cooking alone/with friends).

When supporting domain-awareness and designing respective learning interfaces, a real-life context of smart products usage should be carefully considered also from a human cognitive capacity point of view. In such, visual aids which are able to link learning artefacts with contextual environment of users and smart products are desirable. For example, the effectiveness of location-context based visualization is studied in Paper I to represent virtual smart home or assembly flow in Paper III. In addition, suitability (to the physical context) of interaction means should be pondered. For example, a voice based explanations instead of visuals were studied to produce socially acceptable behaviour of cooking guide, Paper II. Further, for example, it is learned through the user evaluation, that animations are better accepted to explain tasks and processes (e.g., assembly or cooking instructions) and images are more efficient to educate a particular concepts (e.g., smart utensils in cooking scenario or smart tools in assembly lines).

4.3 Awareness – external view

Awareness is one of the functions that essential to support human autonomy (Ryan & Deci, 2000). High-quality awareness puts people in better touch with their needs, feelings, interests and values as well as external conditions. Awareness is foundational to autonomy and competence, supplying its information basis.

Previously we looked on awareness from internal perspectives of mental contents humans may need to satisfy. We explicate awareness in forms of psychological concepts such as schema, self-concept, curiosity, self-assessment, self-efficacy and reflectiveness. Here we aim at looking further on *awareness from external perspective of behaviour*, human needs and abilities to influence the surrounding environment, as visualized in Figure 18.

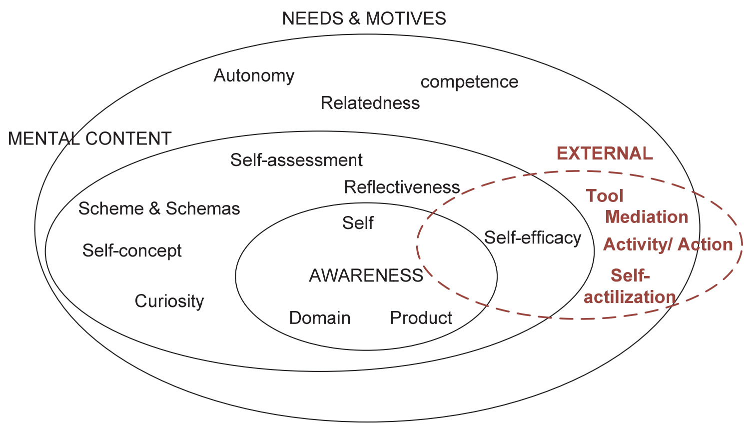

FIGURE 18 Internal and External views on Awareness

The human desire to acquire new capacities is as ancient as our species itself. We have always sought to expand the boundaries of our existence, be it socially, geographically, or mentally (Bostrom, 2005). Human capacity of awareness to be cable of influencing the world can be enhanced by technology. People desire to become more capable and powerful by using technology.

In fact, there is a Transhumanism (or Human Plus, H+) a social and philosophical movement that explores the uses of technology for the positive transformation of human physical and intellectual capacities (McKibben, 2003; Bostrom, 2005; More & Vita-More, 2013). Transhumanism' theorists support the convergence of existing and future technologies promising advances in Artificial Intelligence, bio-/nano wearable and implant technology, virtual reality technologies and cognitive science. Transhumanism is very popular nowadays in media, literature and movie industry (e.g. Matrix, Dan Brown's Inferno). Furthermore, it is also controversially debated in public opinions, criticized and warned for that emerging human enhancement technologies would be available to those with financial resources, thereby exacerbating the gap between rich and poor and creating a "genetic divide" and ”who is making a decision about such technology; and is this an individual choice”. Transhumanism is somehow seen to be influenced by the philosophical work of Friedrich Nietzsche and his thinking and emphasis of *self-actualization* concept (Nietzsche, 1968). And this brings us again to the most important inner needs of humans. Self-actualization has been used in various psychological theories, such as for example in person-centred personality theory, actualization is rather the ongoing process of enhancing individual self than the mental state of individual. Interaction with others and environment is a crucial component of self-actualization (Rogers, 1963). Personality theory is well aligned with earlier discussed Piaget's view on intellectual development process of a child and the need for learning and schema adaptation (Section 2.2). Self-actualization is characterised by such features as efficient perception of reality, acceptance of self and others, autonomy, comfort and frequent occurrence of peaks of experiences (similar to the mental state of flow).

The idea that computer tools augment or enhance human cognition is not new. In fact, the concept of augmentation dates back to 1960s, to work of Douglas Engelbart where he introduced the notion of augmentation system, so called H-LAM/T - Human using Language, Artefacts and Methodology in which he is Trained (Engelbart, 1963). Later since 1990s, augmentation was looked further from a virtual reality (VR) engineering point of view by many researchers (e.g., Biocca, 1996; Sherman, 2002). VR is seen as a new medium (technology) which is able to influence and to enhance the interaction between humans and their environment. The augmentation of human impairment hearing is another example of more recent research (Parker, 2011).

Looking on the research backgrounded on the psychological concepts, around the same time, the Activity theory and the shift from "augmentation" to "mediation" as a theoretical alternative to approach the enhancement of human cognition and HCI design have been introduced (Kuutti, 1996; Kaptenin & Kuutti, 1999). In fact, Activity theory originates from the former Soviet Union, and has its root in the German philosophy of Fichte, Kant and Hegel. The basic concepts of the approach were formulated by Lev Vygotsky (Vygotsky, 1978, 1981). Activity theory has been mostly applied to the information system design (Ditsa, 2003) and learning (Gedera & Williams, 2016).

At some extend *Activity theory* stood out as a *relevant theoretical methodology*, because it provides suitable orienting concepts (such as artefacts as a technological tool and mediation as a process) and external perspectives as well as vocabularies to further analyse case studies discussed in Chapter 3 and to progress with the design of awareness. The following discussion highlights the key concepts of activity theory, visualised in Figure 19 (Engeström, 1987).

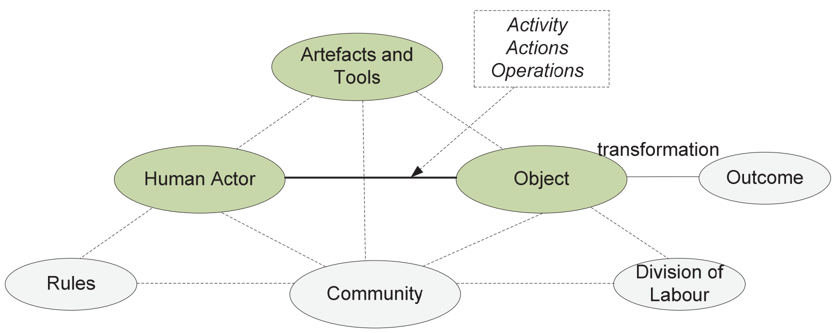

FIGURE 19 The structure of activity theory concepts

Several elements (subject, object, activity, tool, community, rules and division of labour) are formulated by the theory as methodology helping to understand mental capabilities of the individual through his/her interrelations with environment and cultural and social aspects of human activities. As shown in Figure 19, the subject is the human actor who has a "problem space" i.e. the object and does something directed to the object i.e. activity with the help of tool(s) and transforms the object to an outcome. An object can be a material thing, but it can also be less tangible (such as a plan) or abstract (such as a common idea). An object can be shared for "manipulation and transformation" by the participants of the activity i.e. community. Rules encompass norms, conventions, and social relations within a community. Division of labour refers to the organization of a community in relation to the transformation process of the object into the outcome (Kuutti, 1996). A human activity is a form of doing which is driven by certain needs i.e. motive where people wish to achieve a certain purpose i.e. goal. In activity theory, a composition or hierarchy of evolving dynamic operations and actions represents activity. In that sense, it is difficult to distinguish activity and actions because the definition is dependent on what the subject or object in a particular real situation and context is (Kuutti, 1996). Furthermore, activity theory proposes a strong notion of mediation— "all human experience is shaped by the tools and sign systems we use. Mediators connect us organically and intimately to the world" (Nardi, 1996).

Tool can be any artefacts used in the transformation process, including both material tools (machines, instruments), software tools (models, programming language) and tools for thinking (Kuutti, 1996). An essential attribute of these artefacts is that they have a mediating role i.e. an instrument mediates between human actor and the object of doing (Engeström, 1999). Artefacts can be created and transformed during the development of the activity. The assumption is that humans can control their own behaviour from the 'outside', using and creating artefacts (Kuutti, 1996). *Thinking of awareness*, it is useful to look on the classification of tools, provided by activity theory. Primary tools are considered as more simple physical, material tools (e.g., hammer, machine and paper) while secondary and tertiary tools are more advanced (e.g., language, models, systems, virtual realities). Tertiary tools can be also termed as psychological tools and cultural systems (Ditsa, 2003).

Some more concrete instances of tools and activities collected from the experimental studies discussed in Papers I-V, are presented in Table 3. For example, in case study of product conceptualization support (Paper V), primary tools can be understood as 'design brief editor' and 'sketching application' and for the smart home case study (Paper I) primary tools and artefacts are 'smart consumer appliances' and 'home utility systems'. Then an example of secondary tools for all cases are such artefacts as the information management techniques, visual analytics, explanation and learning interfaces discussed in Section 4.2.

Proceeding further to the hierarchy of human activities, examples of operations in the product conceptualization case study are 'sketching of product concept' or 'mastering of design brief' while in case of smart home this can be for instance, 'using smart cooking pot' to prepare the meal. Actions can be illustrated as various smaller tasks related to the previously enumerated activities such as the 'information search on the web' by designer or 'collecting utensils' by user in the cooking scenario. Accordingly, the mediating role of secondary tools is to automate, facilitate and enable these tasks (e.g., annotate, search, link, visualise). Activities may overlap with actions and tasks, however, a few examples to give can be for instance, understanding of water or energy consumption in case of smart environment or grasping of existing design content or patient needs in case of designer support case study and medical emergency response, respectively.

Then awareness, as described in Table 3, is as supplier of information base, which can be viewed as a complex tool and assembling component of all three categories of tools. Alternatively, it can be also understood and classified as *tertiary tool of psychological nature*, which has tight connection to internal world of the user of technology. As have been discussed in the beginning of this chapter, awareness is an important function to enable and enhance autonomy and confidence and may lead to the state of comfort and flow and motivation to accomplish the task and at the same time to enjoying the using of product.

TABLE 3 Awareness as a Tool

Tools	Instantiation of tools	Human activities, actions and operations
Tertiary	Perceived Awareness. It supports inner needs and mental contents: perceived competence, autonomy, relatedness, perceived feeling/state of flow, self-efficacy, etc.	Activities: Cooking, designing products, living in smart home, saving life of patient, assembling cockpit.
Secondary	Common Information Space (CAS), Cooking guide, smart home management system, assembly management system; Sub-tools: Information management techniques, visual analytics, explanation and learning interfaces (annotate, search, inter-link, visualise, reason).	Actions: Search on the Web, collecting cooking utensils, fetching assembly tools, grasping patient needs.
Primary	Conceptual product design: sketching app, design brief editor; Smart home: consumer appliances, utility system, mobile phone; Assembly line: smart assembly tools such screw driver; Emergency management: triage device, ambulance, smoke detector.	Operations: Drawing sketch, editing brief; Using smart pot, fridge or coffee machine; Screwing or gluing the assembling parts; Triaging patient, transporting assisting aids.

4.4 Shaping awareness

In order to exploit scientific and domain specific knowledge in product design, it is important to create a systematic procedures to facilitate this process, for example, by defining the relationships of relevant design concepts and questions to organise design process around them (Saariluoma, Cañas, & Leikas, 2016). Organising knowledge is crucial because it makes it possible to reuse design knowledge and guide design process effectively. Knowledge management in design has been an extensively researched since 1990s (Gero, 1990; Baxter, Gao, & Case, 2008; Liu & Lim, 2011; Chandrasekaran, Josephson, & Bejamins, 1999). Ontologies are proved to be efficient in structuring of domain specific concepts (Chandrasekaran, Josephson, & Bejamins, 1999; Leppänen, 2005; Hao, Guoxin, & Gong, 2013; Poli & Obrst, 2010). Consequently, the attempts to structure design knowledge that explicate the concept of Awareness in form of important psychological and design concepts and design questions discussed in this research is made here. This structure can be called ontology in a sense that it can be seen as a tool which is formed of relevant domain specific knowledge and design questions as well as the answers with aim to organise and to support creative thinking of designer (Saariluoma & Leikas, 2010). With support of explanatory frameworks of mental contents, Activity theory and the needs derived from Self-determination theory of motivation, an objective here is to explicate the contents of knowledge related to awareness construct and hereby to support designers in directing attention to the appropriate knowledge base needed in product design.

As visualised as visualised Figure 20, at one hand, awareness can be framed as a state of mind which is formed by the *mental content*. Such concepts as schema (social-/situation schemas), and in particular self-schema and internal processes (e.g., accommodation, assimilation, apperception, self-assessment) play an important role in forming mental content. Mental content is also related to emotions. Analysis of various schemas is paramount because it helps to understand the motives and feelings people may have, so that designed technology is integral with existing schemas. On the other hand, awareness can be approached as a *tool* of tertiary nature. It enhances human cognition, supports transformation and connects to other individuals and society. Awareness is an essential function to fulfil personal inner needs of perceived competence, autonomy and self-actualization.

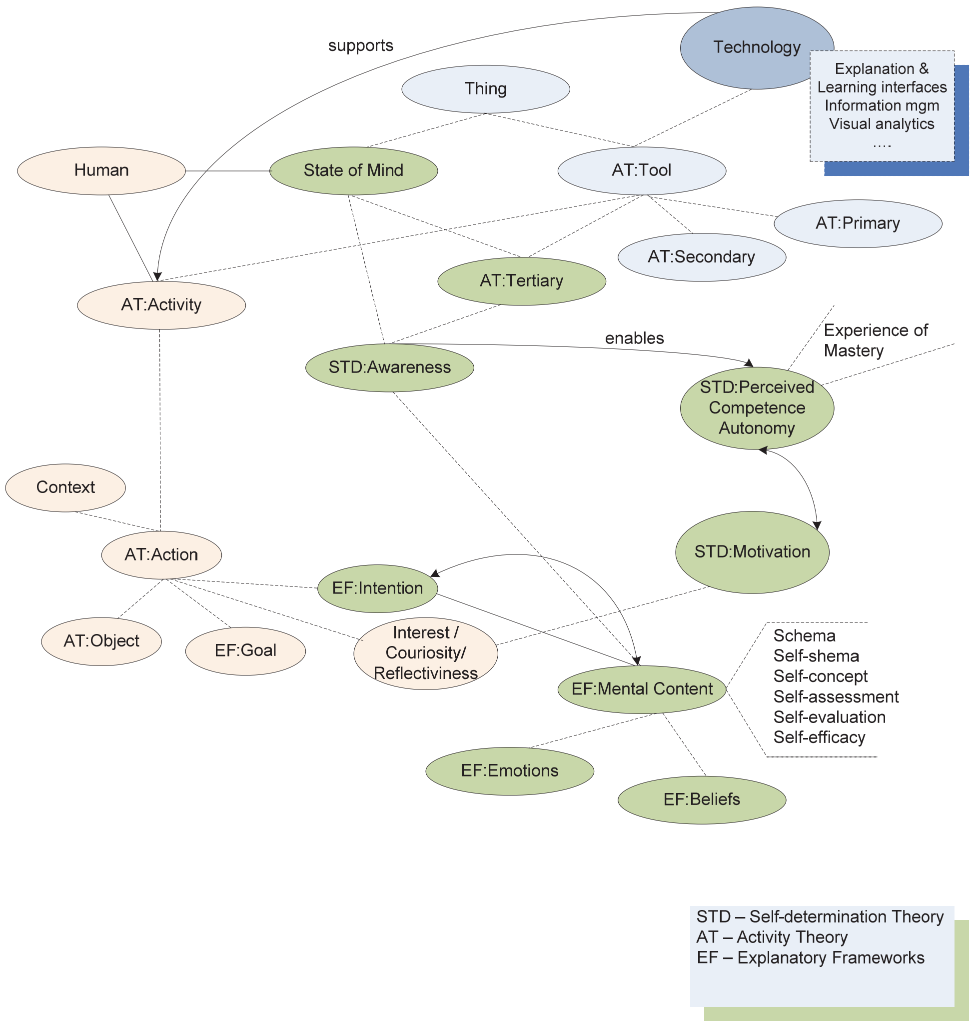

FIGURE 20 Ontological explication of Awareness

Normally, when mastering smart product systems and services, designer goes through the several iterative steps such as *analysis, design, prototype and evaluation*, back and forth before the concept for the new product is crystalized. The design is always purposeful and goal oriented. The goal of design is to transform requirements referred as functions (expectations of the purposes of the resulting artefact) into design descriptions (Gero, 1990). One formal representation of the processes of designing that can be leveraged by designers in more detailed "later" design activities is Gero's Function-Behaviour-Structure (FBS) framework (Gero & Kannengiesser, 2002). It is formed by three classes of variables defining different aspects of a design object: Function (F) variables describe a design requirements or what a product is designed for; Behaviour (B) variables describe what a product means to do to enable function F; Structure (S) variables describe a solution structure or a components of a solution and their relationships. The Awareness as a mental content as well as a tool should be taken into consideration when analysing all sets of described variables.

The initial analysis of design concepts and framing of the problem domain (i.e. understanding variables F, B and S) can be mediated for example by *Design* *thinking* approach which is more suitable for early conceptual stage of product design (Eder & Hosnedl, 2008; Schön, 1983; Cross, 1982, 1990, 2001, 2004, 2011). Design thinking promotes for the integrative approach in product design, facilitated by collaboration of multidisciplinary teams in arts, technology, business and science (Brown, 2008; Kees, 2012; Nussbaum, 2013).

The notion of design as a "way of thinking" in the science can be traced to Herbet Simon's The Sciences of the Artificial book (Simon, 1969) and in design engineering, to Robert McKim's Experiences in Visual Thinking book (McKim, 1973). In 1980-90s, this work has been expanded at Stanford University toward applying the methodology in teaching human-centric Design thinking. Design thinking methodology based methods further developed by Stanford University offer a solution-based approach to solving complex HTI problems that are ill-defined by understanding in particular the human needs. Methods involve the re-framing the problem in human-centric ways facilitated by creation various ideas in brainstorming sessions, and by adopting a hands-on approach in prototyping and testing. Accordingly, the methodology provides designer with sets of iterative design thinking processes/stages (Empathise - Define – Ideate – Prototype - Test) and relevant design-assisting resources that can be used by product designers in their creative design activities (Stanford, 2019).

Looking closer at five design stages of Design thinking:

1. *Empathise stage* aims at gaining an emphatic understanding of the user and the problems that underlie the development of that particular product. By observing, engaging and empathizing with people the ultimate goal here is to understand users' experiences and motivations, as well as the user- and product context (physical, societal, psychological) to gain a deeper personal understanding of the issues involved. The relevant theoretical research and experts can be involved at this stage as well.
2. The objective of *Define stage* is to analyze observations and to synthesize them in order to be able to establish features, functions, and any other elements of the product that will allow to solve the problems.
3. During *Ideate phase* it is important to create many ideas or problem solutions. Various means such as brainstorming sessions, sketching and mind mapping activities can be employed here.
4. *Prototype stage* is an experimental phase and it aims at producing a number of inexpensive mockups, "scaled down" versions of the product or specific service or even features found within the product, so that solutions generated in the previous stage can be further studied. The implemented prototypes are validated here with the users and either accepted, improved and re-examined, or rejected on the basis of the users' experiences. As a result of this stage, the designers should have a better view of how real users would behave, think, and feel when interacting with the product.
5. *Test phase* is used derive as deep an understanding of the product, conditions of its usage and its users as possible towards the finalization of solutions.

More specifically, *taking awareness aspects in design* would then instantiate and focus the previous steps to the *following activities:*

1. Analysing a human actor - his/her mental content to understand the need to support awareness;
2. Analysing operations, tasks and activities at one end and respective tools/artefacts that can enable awareness at other hand;
3. Ensuring mediation and seamless penetration of these technological artefacts into functional tools and tasks in hand to support the perceived autonomy and competence.

Analysing a human actor should include the understanding of self-determination needs, mental content and composite schemata of individual(s) and their related psychological constructs (self-schema, assimilation, self-assessment, self-efficacy) according the definitions given in Section 4.2.1 to support the personal needs of perceived competence and autonomy

The process of *activity analysis* involves the understanding the primary and secondary tasks (actions), where technology is involved and identifying the demand to support various forms of awareness discussed in Chapter 4 (Figure 13). The understanding of structure of human action should help in the design of requirements for the product under development. For example the action ontology (as visualised in Figure 20, light red colour) which expresses main set of attributes, - intention, interest, object, instrument, actor, context and sub-action, essential to describe an action, can help here (Saariluoma, 2009).

The human *actions* always have *goals* or when mentally represented it is represented by *intention* and *interest* which is thus related to *motivation* to perform a certain action. Progress in goals pursuit makes us feel satisfied contributing positively to self-efficacy, autonomy and competence as discussed in Section 4.2.1 (Figure 14). Further interest, intention and motivation are interlinked by emotional aspect. *Emotions* are influential with respect of actions people choose (Saariluoma & Jokinen, 2014). Understanding these concepts may help to reason about how/what artefact can support awareness and thus lead to perceived feeling of autonomy and/or competence. As discussed in Section 4.3, actions are targeted always at some *object* and people use technologies as a *tool* to support their actions towards a pursuit of their goals. Actions always take place in some *context* (physical, social, psychological) which need to be analysed and taken into design account. In this sense, for example the Offenbach theory of product language (Steffen, 2007) leveraged in the designing of ontology to support designers' activities (Paper V) can be used to analyse various context and emotional response created/targeted while interacting with product.

Of course, it might not be feasible and realistic to include many design artefacts to support awareness and consequently, perceived autonomy and competence. The objective is rather to identify the tasks and user inner needs, where awareness can be supported. The awareness supporting attributes/artefacts may be simple such as for example, providing some product-specific setting-means or more complex such as introducing, for example, new innovative interface elements in form of knowledge supply and visualizations to increase the learning and motivation outcome of the task to support personal self-concordant goal. Though, the important is that awareness-related attributes are explicated in a theoretical psychological (or, e.g., sociological if relevant) terms.

The *infusion of awareness-aiding artefacts* should happen during the detailed product design process. An artefacts in various forms such as explanation and learning interfaces and others forms discussed previously, should target the support for the accessibility of self-concepts and self-assessment as well as a product- and domain-awareness towards the trust, likeness and the desire for technology (see discussion in Sections 4.2.1—4.2.3).

Subsequently, during the analysis stage, for each user task, the questions to be answered by the designer may include the following:

- How does this activity relate users' various forms of awareness? How this activity/task can facilitate different forms of awareness? Can this be supported by technology?
- How does the activity affect this particular user' perceived experience of autonomy and competence? How the clarity of activity and its goal can be improved?
- Is the recipient known to understand his/her mental content and to form an appropriate/accurate user model? How such understanding can be supported by product?
- How can this activity facilitate reflective connectedness? How reflectiveness can be supported by product?

Moreover, the questions introduced in Tables 4-6 summarise further the aspects, discussed in the course of this thesis, with aim to facilitate the designer work towards the mastering of various forms of awareness, related to the particular task, which the technology/products system is intended to support.

TABLE 4 Mastering 'Self- awareness'

Awareness	Self-awareness (definitions are provided in Section 4.2.1)
Design questions	• How the elements of self-concept can be acquired by product *before its first use and in the duration of usage?* The example of methods may include questionnaires or monitoring means. • How the Human-Technology Interaction pattern can be made more familiar? Ref. to script discussion in Chapter 2. • How self-assessment of recipient can be supported when using this technology? E.g., by comparable analysis of outcome of particular activities • How self-efficacy can be supported by design? E.g., by monitoring (and indicating) progress and by providing the supportive encouraging explanation content
What (type of content)	Reflective, situated
How (means)	E.g., visual analytics

TABLE 5 Mastering 'Product Awareness'

Awareness	Product Awareness (definitions are provided in Section 4.2.2)
Design questions	• How the functionality of products system can be made more transparent? • How the purpose of the system can be made clearer (e.g. situated)? • How the reasoning of the system can be more visible? • What types of knowledge attributes (are they related to physical world, social aspects or individual behaviours) contribute to visibility? • How the vocabularies operated by the system can be clarified better? • How the prompts produced by the system helping? How they contribute to "why and "what""? • How the justification of interaction with recipient can be improved? • How knowledge ca support differentiates types of recipients (i.e. personalities)
What (type of content)	Scientific, analogy, cognitive, empathy, persuasive
How (means)	E.g. explanation interfaces and artefacts, system settings, visual aids

TABLE 6 Mastering 'Domain Awareness'

Awareness	Domain awareness (definitions are provided in Section 4.2.3)
Design questions	• Who is the learner i.e. user of the system (personality, interests, novice vs experienced)? • What is the objective of learning (gaining new knowledge, skills or improving motivation and confidence)? • What background psychological / sociological theory exist to support the particular objectives of learning?
What (type of content)	Scientific, societal, domain-specific
How (means)	E.g. learning interfaces and artefacts, visual aids

When designing awareness-aiding artefact, designer should consider the quality of the proposed infusions. As outlined in Section 4.2.2, this quality should comply with such aspects as fidelity, simplicity, being innovative and natural for this particular recipient (see Figure 15 for more details).

5 CONCLUSIONS AND FUTURE DIRECTIONS

The aim here is to summarise the contribution of this research and to provide with aspects of future research directions.

5.1 Contribution of this research

In product interaction design, the design ideas should be based on understanding of human dimension i.e. knowledge of human performance, mind and social life. Numerous complementing approaches have been developed to incorporate the human knowledge into technology design thinking. Common examples extensively discussed here include human factor and usability research, context and situation awareness as well as more recently emerged human value-oriented and worth-centred developments. Related approaches include emphatic design, ethical and inclusive designs.

These different approaches examine the field of product and in particular, HTI design from different complementing points of view such as for example, the human factors, ergonomics, usability and HCI emphasised human performance and easiness of interaction with technology. Instead, UX research, emotional design and value- and worth-centred approaches rely on emotion, motivation, personality and action based ways of interaction design thinking, - making people want to use and like the technologies (Saariluoma, Cañas, & Leikas, 2016). The awareness study presented here complements the latter approaches. The awareness-aided product can facilitate the satisfaction of inner human psychological needs and thus be an effective tool for improving individuals' well-being hereby positively contributing to the acceptance of technological system. This thesis has explored the role of awareness as a psychological construct in determining human behaviour and consequently its influence on how humans respond to the technology. The design principles and general procedural guidelines described here are therefore intended to alert designers to concerns of awareness, motivation and inner psychological needs such as perceived autonomy, competence and relatedness, so that they will be more likely to include them in their early product design processes.

The presented framework in form of ontological tool defines vocabularies and design questions that the designer may consider in mastering of various types of awareness. The vocabularies and design questions are defined to answer the research questions introduced by this thesis, more specifically the meaning and the elements which constitute the awareness in various application contexts as well as how these elements can be taken into design in early phases of new product and service engineering.

The *first research question (RQ1)*, ‘What awareness means in various real-time context’, is approached by examining such application domains as smart home, aircraft assembly line, emergency events management and collaborative product design (Chapter 3). Each domain has been analysed from awareness point of view. Extensive user research has been facilitated by analysing the users of the systems in action and through prototyping and evaluating of developed research artefacts. The focus in each study is put on the particular aspect of awareness and what it gives to the users. In each study, the extensive ontology-based knowledge models have been defined to provide users with various knowledge aspects to facilitate awareness.

For example, in smart home case, awareness aims at empowering and inspiring user to supervise own home and thus at contributing positively on the uptake of home technology. Accordingly, various aspects of living environment and related visualization views such as the details of the house, areas and rooms, materials and furniture as well as the services and technology situated and used at home made available for query and reuse to support awareness-aided applications and service. The examples of application, a few to mention, are house maintenance, elderly care and technology education.

In the study related to interactive cooking guide application, in particular explanation and learning interfaces have been researched to support users in understanding the functionality of the product and the domain towards the better acceptance of sensory-based modern technological systems. The user awareness means here the understanding of practical information related to the cooking process, the functionality of different sensors and the usage of cooking utensils as well as the reasoning behind selection of particular recipe or certain ingredients and meals’ components.

In product assembly line study, awareness aims at providing various actors in the systems with better understanding of the status of the assembly floor. Awareness elements constitute such information as various statuses of equipment and scheduled tasks and the usage of resources and assembly tools. This information allows optimising and changing working processes with necessary involvement of human reasoning. The methods based on machine learning algorithms and anomaly detection are not capable to accomplish this need alone.

In case study related to medical emergency response, awareness is approached from “simplicity” point of view. The emergency is a complex event, which involve various types of information needed, to successfully support actors involved in emergency management tasks. Putting the patient-related needs and consequently, awareness of the state of the person, affected by emergency event into the center of the discussion helped us to understand the needs and the requirements to the awareness model. Mastering the real-time information such as triage measurements and location of each victim (i.e. field, ambulance and hospital) has enabled to run a rescue processes in parallel, therefore saving time and becoming more effective in saving lives.

In the product conceptualization study, awareness is approached from product designer point of view. This research has focused in particular on how awareness in form of respective contents and knowledge element can support confidence and motivation of designers to produce innovative product concepts. The awareness has been formed from knowledge elements related to the work of other designers as well as from knowledge of domain and other interdisciplinary information, which is crucial in the product design. The Design Science approach has been utilised in each study to understand the meaning of awareness by experimenting and validating a proposed research ideas and prototyped artefacts with users.

The *second research question (RQ2)*, 'What are the elements that constitute awareness', has been approached by systematically analysing the domain studies and by extracting the elements and features that contribute to the creation of perceived awareness. This process has been further facilitated by the discussions with users supported by numerous workshops and processing of the feedback collected during prototype evaluations. The results of analysis are presented in Chapter 4, Table 3. At the next step, the identified features are abstracted and grouped into bigger assembles, named Self-awareness, Product-awareness and Domain-awareness towards their further analysis and explanation supported by existing explanatory frameworks and psychological theories discussed in Section 2.2. Self-awareness is represented by features, which help user to pay attention to own abilities as well as to understand own role, state and place during interaction with technological system. Product-awareness constitute the features that make user comfortable with product, be able to control it and to understand about how product works and why product works in a particular way. Domain-awareness is created by product, providing users with new knowledge and skills in the domain of the product. A few examples to give, in case of cocking guide application, this may relate to learning of new recipes and smart utensils, alternatively, in product conceptualization case, this can be providing designer with new design techniques, trends and cultural insight when mastering new product concept. The features designed in the product that support users in enabling of aforementioned types of awareness may lead to perceived feeling of autonomy and competence, thus positively influencing the liking and general acceptance of product.

To answer to the *third research question (RQ3)*, 'How to design awareness taking into account well established psychological constructs of human universal psychological needs and motivation', the user psychology and psychological theories of motivation and activity theory as well as the previous studies on awareness in course of HCI research have been taken as a ground. Awareness is examined from internal perspective of mind (Sections 2.2 and 4.2) and external perspectives of behaviour (Section 4.3). Foundational analysis, as a method to analyse the content of experimental concepts through their re-composition and reconstruction to find more accurate concepts to explain awareness has empowered this research. At one hand, awareness can be explicated as a state of mind, which is formed by the mental content. Such concepts as schema (social-/situation schemas), and in particular self-schema and internal processes such as accommodation, assimilation, apperception and self-assessment play an important role in forming mental content and awareness accordingly. On the other hand, awareness can be understand as a *tool* of tertiary nature. It enhances human cognition, supports transformation and connects to other individuals and society. Awareness is an essential function to fulfil personal inner needs of perceived competence, autonomy and self-actualization.

Above described concepts are important and influential on human behaviour. Consequently, they must also have their role in how humans respond to the technology. By investing and creating of various artefacts, which aim at supporting/enabling awareness, both as a state of mind and/or as a tool towards self-actualization, the user experience and thus the acceptance of technology-based systems in various modern technology-intensive products and services can be better managed.

Ontologies are utilised here to facilitate designer with systematic knowledge and vocabularies to be taken in product design hereby mediating psychological knowledge to technical designers. The ontology of explanation interfaces (Figure 15) and Learning taxonomy (Figure 17) can help designer to consider the goal and the content of explanation and leaning services as well as to address the quality of those by such measures as relevancy, fidelity, and innovativity. The ontology of explanation interfaces, which is based on the previous research resulted from the fields of computer science and philosophy, has been extended in this study to address better such aspects as, situatedness and reflectiveness, which are essential for real-time application cases. Finally, the ontological explication of awareness (Section 4.4, Figure 20) and the design questions (Section 4.4, Tables 4-6) are defined, to help designers to think about various types of awareness. The answering to the defined design questions aims at helping designers with mastering of what kind of requirements to knowledge, their construction and dimensions are needed to support the incorporation the awareness aspects into the design of future technology-intensive products and services in consumer and professional context towards their better acceptance. The defined ontological framework is a further step to support an explanatory design as it provides design tasks-relevant questions and respective theoretical awareness-specific knowledge base to generate explanatory framework that connects science (psychology, philosophy, cognitive science) to design.

5.2 Future research directions

Facilitated by Design Science research, domain studies discussed here, have used traditional well-established usability assessment methods such as questionnaires to evaluate elements that support the achievement of awareness. In the future, it would be useful to look on more targeted criteria and methods utilizing verbal protocols and interviews to understand the participants thinking process towards the assessing awareness in a user interaction design.

Further, this thesis is finalised at the time of technological hype of Artificial Intelligence (AI), self-driving cars and new service platforms to support an immersive user experiences. Consequently, in the future it would be interesting to investigate how perceived awareness can be taken as a constraint, that can be imposed on AI systems. More specifically, how awareness-related constructs can be translated into constraints and learning/reasoning methods that meet those constraints. To recommend relevant approaches in AI context, the AI system must have knowledge about what kind of constraints each algorithm can deal with. This knowledge may reside for example in an "Awareness Ontology" that describes and connects constraints and reasoning/learning methods.

From application case point view, it is planned to look on other technology-intensive domains. One example of those is Smart cities. It is envisioned that in the future cities will incorporate various technologies driven by advances in artificial intelligence, predictive analytics and IoT, into its physical infrastructure in order to make cities more sustainable, ecological, energy efficient as well as to improve public services, make its citizens safer and improve overall quality of life. Many solutions provided by cities such as smart grids or CCTV cameras are very important, however, they have an invisible effect of citizens' life and behaviour. On the other hand, there are many technological solutions such as digital payment, property (apartment, bike, car) sharing, dynamic public transport scheduling, smart trash management, etc., that can change the daily life of citizens and that citizens can either use, adopting it or not. Various typed of awareness will come into the picture and will need to be addressed by citizen-centred design to improve the adoption of such new technology.

Furthermore, while today's smart products are mostly referred to in the consumer context, in the future smart products will more and more penetrate working environments. In addition, due to the increasing expectations from smart products, future smart products systems will be more complex than existing ones. Working environments will also place much more importance on the human dimension, making the most of workers' knowledge, skills, and cultural backgrounds, but at the same time responding to workers' needs for continuous learning and training. The smart workplaces of the future will be based on methodologies for enhancing flexible, safe, and smart production, where adequate levels of automation are applied, while maintaining a level of employment with highly satisfied and skilled workers and, at the same time, ensuring competitiveness. These trends will require new smart products concepts and technologies for the optimized use of workers' knowledge and cognitive capabilities, to enhance the interaction of humans and technological systems and to assist workers in the quick learning of new tasks and processes. These new interaction models should take into account the skills, capabilities, motives and personalities of the user, to create truly personalized and thus effective interaction systems. Consequently, understanding these concepts and mastering respective knowledge in product design will be paramount. The ontological framework resulted from this research can bring values here by providing respective knowledge from psychology of awareness, dynamic user psychology, cognitive science and philosophy to support a creative designer' thinking in design, development and innovation of intelligent behavior of smart products systems.

YHTEENVETO (FINNISH SUMMARY)

Uudenlaiset teknologiat avaavat uusia visioita ja liiketoimintamahdollisuuksia tuotejärjestelmien suunnittelussa ja kehittämisessä ihmiselämän eri alueilla. Nykypäivän teknisiä tuotteita tarkasteltaessa voidaan kuitenkin tunnistaa tietyt suuntaukset, kuten tuotteiden monimutkaisuuden lisääntyminen, tuotekohtaisen tiedon lisääntyminen ja monimuotoisuus. Näin ollen yhteentoimivuuden lisääminen on tarpeen avoimissa ympäristöissä. Käyttäjä unohtuu helposti valtavan teknisen monimutkaisuuden vuoksi, jota suunnittelija ja palveluntarjoaja joutuvat käsittelemään. Suunnittelutyön helpottamiseksi ja teknologian kehityksen tasapainottamiseksi syntyi inhimillisiin arvoihin perustuvia lähestymistapoja, kuten arvokeskeistä, empaattista sekä esteettistä suunnittelua. Motivaatio on tunnustettu tärkeäksi tekijäksi teknologian suunnittelussa. Se on olennainen käsite selitettäessä, miksi ihmiset käyttävät teknologiaa ja missä määrin erilaiset suunnittelumallit auttavat motivoimaan yksilöitä käyttämään tiettyä tuotetta. Siksi motivaatiorakenteita ja niihin liittyviä psykologisia teorioita, kuten sosiaalisen, kognitiivisen ja psykologisen ihmisen tietoisuuden teorioita, tulisi ottaa laajemmin huomioon teknologian suunnittelussa. Näin käyttäjälle saadut hyödyt voidaan maksimoida ja siten tehdä teknologiasta hyväksyttävämpää.

Tässä väitöskirjassa tarkastellaan tietoisuuden roolia ja vaikutusta siihen, miten ihmiset reagoivat teknologiaan. Tietoisuus on tärkeä rakenne, koska se auttaa ihmisiä tyydyttämään psyykkisiä tarpeitaan osaamisen, itsenäisyyden ja läheisyyden suhteen. Sitä pidetään yhtenä sääntelyprosessin osana, joka tukee erilaisia motivaatioita. Sisäiset psykologiset tarpeet voivat toimia tarpeina, jotka on tyydytettävä, ja motiiveina käyttäytymiselle. Teknologia, joka tukee tarpeiden tyydytystä, helpottaa teknologian käyttöä.

Ensisijaisesti tarkastellaan loppukäyttäjän näkökulmaa teknologian käytössä, mutta tutkimuksen päätavoitteena on kuitenkin tukea palvelunkehittäjää ottamaan huomioon tietoisuuden näkökulma nykyaikaisissa tuote- ja palvelusuunnittelussa. Työssä määritellään suunnittelukysymysten ja sanastojen avulla yleiset suunnitteluperiaatteet, jotka auttavat suunnittelijaa soveltamaan systemaattista tietämystä tietoisuudesta teknologian suunnittelussa. Tarkemmin sanoen tutkimus pyrkii vastaamaan seuraaviin kysymyksiin: mitä tietoisuus tarkoittaa eri reaaliaikaisissa sovellusyhteyksissä, jotka muodostavat tietoisuuden, ja miten suunnitella tietoisuutta ottaen huomioon ihmisten yleiset psykologiset tarpeet ja motivaatio.

Tämä tutkimus perustuu laajoihin sovellusaluekohtaisiin tutkimuksiin, jotka toteutettiin neljän tutkimushankkeen puitteissa vuosina 2010–2017. Lisäksi tässä työssä on hyödynnetty laajasti vuosikymmenien tutkimusta HCI:n ja kognitiivisen tieteen alalla. Erityisesti motivaation itsemääräämisteoria, mielensisällön selittävät rakenteet ja toiminnan teoria ovat antaneet tutkimukselle joukon filosofisia käsitteitä ja psykologisia näkökulmia. Niitä on käytetty tietoisuuden ja sen teknologisten ulottuvuuksien integroimiseksi kokonaisvaltaiseen teoreettiseen tutkimuslähestymistapaan.

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ORIGINAL PAPERS

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INTERACTIVE HOME SUPERVISION APPLICATION -THINK VISUALLY

by

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Interactive Home Supervision Application

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***Abstract*—The advances in distributed sensing and wireless communication enable pervasive home applications which are information-rich. Hereby the integrated access and management of heterogeneous information becomes an increasingly important research topic. Moreover recent popularity and advances in visual aids (Google maps, 3D computer graphics, PS games, etc.) call for the more attractively intuitive user interfaces to manage home data. This work describes the ontology based home management approach which facilitates integration, interactive visualization and necessary sharing of heterogeneous home data.**

Keywords-Intelligent home, data management, visualization

I. INTRODUCTION

Recent advances in pervasive computing, deployment of RFID devices and wireless sensors enable novel types of home services from various application domains such as e-health, assistive living, home monitoring and control. The examples of applications are span from security and surveillance (alarms, events, keeping information about residents/non-residents) to monitoring of consumption of home resources (measuring, logging and comparing water and electricity consumptions) and status of appliances including their maintenance and history. As a result extensive heterogeneous information can be easily generated within smart home environment. Nowadays user has to visit several places, use several different devices and interfaces to get the comprehensive view of the house.

It is envisioned that in future smart home will contain many more RFID enabled and measuring technology embedded devices and systems for sensing various physical phenomena and activities of the home. Obviously with growing amount of heterogeneous data generated in home, there is a growing need to support heterogeneous data aggregation, representation and sharing.

The vision of the 'smart' home is that in the future our homes will be so automated and smart that we will barely need to think about every day tasks. While most of smart home research has centered in applying ubiquitous computing technology in the automated home systems (controlling lighting and scheduling home appliances) [25][26][27] or on providing support for service developer and end user programming [28][29][30], there has been little focus on enabling and attracting home occupants to take control of the technology in their home. We believe that the advances in human-computer interfaces, which are handy, intuitive in visualization, and easily customizable still to be addressed to facilitate and inspire user to supervise own home. This work addresses the above discussed needs developing VantagePoint prototype application, which facilitates the user with some home supervision tasks. In the following, section 2 outlines recent background technologies emerged around smart home and being utilized in the prototype development. The VantagePoint tool and several application use cases developed to demonstrate some managing and visualization ideas and concepts are presented in section 3. Section 4 concludes the research outlining aspects of future work.

II. BACKGROUND TECHNOLOGIES

In recent years, there has been a lot of interest in applying ubiquitous computing technology in the home. The effort has been made to address the seamless integration of devices and services solving the compatibility problems between different types of devices. One of the most prominent standards emerged is Open standard gateway initiative (OSGi) [16]. OSGi facilitates the connection and management of networked devices and makes the deployment of home based technology much easier. Implemented by Java it is platform independent. Multiply services hosted by different service providers can be easily hosted by single gateway platform. Its management functionalities include installing, activating, deactivating, updating, and removing services. Effort has been also made towards context awareness and delivery of personalized end-user services. Many of the proposed frameworks are based on OSGi technology [17][18][19].

Semantic approaches applied to the domain of real physical environments, is another research direction to address device interoperability and autonomy, and personalization aspects in home service delivery. Inspired by Semantic Web, ontology languages such as Web Ontology Language (OWL) [1], ontology based technologies and tools have gained much attention recently in particular to represent and effectively query the diverse heterogeneous data types found in home [15][17][20][21]. Ontology based data representation allows to describe home contexts semantically and share common understanding of the structure of contexts among users, devices, and services. Semantic models enable a formal analysis of the home domain knowledge, such as performing data reasoning and decision making.

With recent advances in computer systems and graphics capability, the information visualization has become a hot research topic. On the same time the computer games industry has come up with new approaches for presenting data on computer screens in an illustrative and impressive way. It is succeeded in effectively exploiting different kinds of visualization techniques (isometric perspectives, 2D/3D views, spatial relations between objects, etc.). Nowadays many of the approaches implemented for educational or scientific purposes are inspired by computer games [24]. Thinking visually in three dimensions benefits the sense of wonder and user interaction connected with the application of scientific and information visualization technologies [22]. Interactive visualization and interactive graphics may directly portray the description of the data or present the content of the data in a completely innovative form facilitating zooming, filtering, and finally obtaining details on demand.

However advances in visualization are not yet the part of intelligent home technology. The user interfaces available today are graphically simple however technically complex. Moreover there are too many control systems in the house with own control nodes and dedicated user interface. Effective aggregative visual interface would enable user to observe, manipulate, and understand the state of the house, and interact with data letting the user query information in real time.

Inspired and taking benefits of identified trends and technologies and addressing the above discussed needs we have extended early developed simulator tool called VantagePoint [31].

III. VANTAGEPOINT TOWARDS HOME DATA MANAGEMENT

VantagePoint is a Java application that is able to visualize, query and edit semantic context information described in Web Ontology Language using Jena Semantic Web framework [2]. VantagePoint provides a possibility to build contextual models of different environments without requiring any particular knowledge of semantic technologies such as ontologies. Through simple graphical operations users are able to create and edit the semantic context models and thus simulate virtual or existing environments. By populating the models with illustrative 3D icons, the different objects can be concretized and located in their exact positions. The semantic context models created with VantagePoint are saved as 'owl' files that can be used by applications or published as context sources for more dynamic use.

A. Visualization in VantagePoint

VantagePoint visualizes semantic context information by presenting contextual information and spatial relationships effectively by visualizing instances in their actual locations. VantagePoint also offers the possibility to view the visualization from multiple angles and with different perspectives and it exploits both two- and three-dimensional views. VantagePoint provides three distinct views to the visualized model: the text view, the edit view and the isometric view. The text view shows the visualized context model in a textual form. It enables to examine the structure of the OWL file and see how the changes made in the visualization have affected the model. The edit view is a 2D 'ground plan' view of the environment that has been visualized, whereas the isometric view (see Figure 1) visualizes ontologically described environment more impressively from a three-dimensional perspective. The purpose of the two-dimensional edit view is to enable more accurate editing operations. In general, 2D views are considered better for navigating and measuring distances precisely, establishing precise relationships and performing spatial positioning [3] [4]. The purpose of the isometric view is to visualize models in a more impressive way and to provide a better general view of the contextual environment. It is stated that by using the isometric projection, spatial relationships between objects can be seen within wide environments [5]. Furthermore, the isometric projection has proven its effectiveness in visualizing three dimensional spaces in such popular computer games as 'The Sims' [6] and 'SimCity' [7].

Figure 1. The isometric view of VantagePoint

The Model-View-Controller (MVC) framework was selected as a starting point for the visualization implementation of VantagePoint. The MVC framework is a widely used architectural approach for interactive applications. It divides functionality between objects involved in maintaining and presenting data to minimize the degree of coupling between the objects [8]. In the Model-View-Controller architecture, objects of different classes take over the operations related to the application domain (the model), the display of the application's state (the view), and the user interaction with the model and the view (the controller) [9]. The structure of the Model-View-Controller architecture is presented in Figure 2.

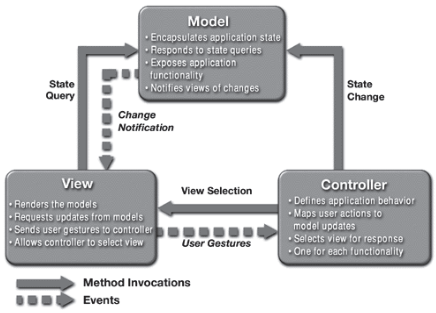

Figure 2. The Model-View-Controller architecture [9]

B. *The Context Taxonomy of Vantage Point*

As discussed before, VantagePoint forms semantic models of different environments and visualizes them. More specifically, VantagePoint reads OWL files and searches for individuals that belong to a predefined VisualComponent class. Only individuals that belong to the VisualComponent class are visualized, all other data that is irrelevant or impossible to visualize are ignored. The VisualComponent class is divided into two separate subclasses - Item and Area. All things visualized fall into these two classes. If the ontology does not contain the class VisualComponent, only the text view is created and the user can make queries to it. The context of the VantagePoint world is defined in an ontology called 'VantagePoint.owl', which holds the class and property definitions of that context. Figure 3 presents the structure of the VantagePoint context model.

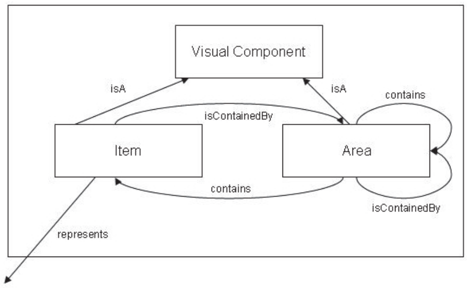

Figure 3. VantagePoint context model

VantagePoint enables also the manipulation of the context models. The manipulation consists of editing operations such as removing, adding, moving and rotating of instances. The moving and rotating operations edit individuals' properties. For example, location properties are changed by moving instances in the visualization and the 'contains' property is automatically calculated from the new locations of the moved instances. When the user removes an area from the visualization, VantagePoint automatically removes all the instances that were contained by this area. [10]

C. *Case Study: AmIE - Ambient Assisted living for elderly*

AmIE (Ambient Intelligence for the Elderly) is an international ITEA project with various partners involved from four European countries, http://www.amieproject.com/. The main goal of AmIE project is the development and testing of a complete intelligent, distributed service system whose target is to improve the quality of life for the elderly [11]. The AmIE project provides an interesting use case for VantagePoint as there is a need first to design the living environment semantically modeling various aspect of elderly adult life and then instantiate it. By realistically representing the home environment elderly adults and also their relatives and nurses are, for example, able to remotely examine the current state of the elderly and the home.

On the other hand, VantagePoint can provide support for application developers who need contextual data in their design work. By enabling the simulation of different context events with graphical editing operations developers are able to test their applications with VantagePoint and to see the operations as in real life and to better notice practical errors without expensive test laboratories.

Besides of modelling the static home environment, VantagePoint allows integrating additional data from various sources into a single contextual model. By visualizing this model, VantagePoint provides an access to a large amount of information by just examining the different views provided. In general, visualization enhances the adoption of information as it links the two most powerful information processing tools known – the human mind and the modern computer. In the following we present some use cases and ideas illustrating how VantagePoint can support integration and interactive visualization of various heterogeneous home data. The use cases are selected from several application domains such as general home maintenance, personal healthcare and assisted living enabled by sensing technology and other means such as self-assessment questionnaires used to collect welfare profile data.

Even today's home, equipped only with a few televisions, PC, play station and automated air and heating control system brings often difficulties to find user manuals, price, care and warranty instructions. In the future home, goods (the sofa or TV, for instance) bought from nearest story and equipped with tiny sensor (e.g. RFID tag) and communication capabilities will be able to report on detailed history about its production features, use and repair. A billion of information pieces will be available around. Thus in VantagePoint we have experimented looking for the means on how such information can be organised and linked to home instances for their further examination and reuse. For example, VantagePoint allows attaching different kind of reports to an instance. If a model contains a television, it can be linked with a report providing more information about that particular television, such as the model of the television, services and features available, and useful history such as, when it was bought, repaired, and if it is still under warranty (see Fig. 4). Similarly, a floor can be attached with a report providing information about the material of the surface, price, heating type, possibly sensor integrated, care instructions, and other useful things which often urgently needed, but not on hand. It is then possible to search over reports, to check for repair history or to subscribe to particular parameters and being accordingly notified for example in case of warranty expiration. Such reports can be read from FRID data attached to smart home goods or downloaded for example from the Internet company sales and electronic commerce sites.

For the assisted living and healthcare monitoring, the real world scenario inspired us to experiment with sensor systems, involves a 75-year-old woman named Anna who lives in her own apartment. Anna's current wellness information is estimated by combining data from several sources. The system collects sensor data from wearable sensors, environment sensors, wellness self-evaluations, social proximity (nurse, family, friends,…), health record information, etc. The online welfare profile can be utilized by Anna herself, relatives and health care professionals to personalize the services offered to Anna. The system stores some information from bed sensors about the sleep quality, about how many times certain electrical appliances are used or different doors opened during the day, how many phone calls or visitors Anna had today, etc. Anna's mental wellbeing is analysed through interactive games, such as memory games. In addition, information from possible medical measurement devices, such as blood pressure meter, is collected by the system. Anna can give her own assessment on her current condition to the system by touching a corresponding smiley face. A nurse or a family member visiting Anna can give their opinion on Anna's condition using the same method or by using a web or mobile phone service. This information together with sensor information described above is combined to indicate Anna's current condition with e.g. "mood light indicator".

Model and purchasing information 	Sony Bravia-KDL-40X4500
	Purchased 12.12.2007
	Price 850 €
	Guarantee period until 12.12.2009
Services & attributes	BRAVIA ENGINE 2 intelligent noise reduction
	Motionflow Pro technique for fast movement picture (e.g. sports)
	DLNA-home web technique
	x.v.Colour technique which provides double amount of colours
	USB Photo Viewer, for watching digital photos from TV
	Picture Frame Model -state
	CrossMediaBar user interface
	24p True Cinema state
	WALKMAN, iPod, Blu-ray Disc -player and Playstation3 –plug ins
	Support DVB-T- and DVB-C-for high-resolution broadcasts
Service History	Picture tube changed 10.08.2008 Tapiolan TV-huolto http://www.tapiolantvhuolto.fi/, phone 09-85696888

Figure 4. A television report

To address the elements introduced in scenario, we have experimented with the data produced by different sensors. Two types of sensors have been integrated to the VantagePoint context models: SimuContext sensors [13] and Carerider bed sensors. As we do not have much of real sensors to verify our developments and concepts, SimuContext tool helped us to simulate ones. These simulated context sources emulate the behaviour of life context sources. SimuContext enables the creation of virtual sensors of various kinds that are abstracted as context data producing entities. The virtual sensors generate context information with configured value and event models. Those models can be predefined values or generated randomly to model the un-deterministic behavior of the physical environment.

The SimuContext is lightweight, Java based and easily extendable, which makes it an attractive framework to be integrated with VantagePoint. The integration is carried out by allowing the adding of virtual SimuContext sensors into the VantagePoint context models and enabling users to configure and manage them through VantagePoint graphical user interface. We can imagine that in the future sensors and sensors embedding devices purchased from the nearest shop can be similarly integrated and controlled using VantagePoint interface. The data events produced by the sensors are stored into a separate semantic model and the data can be retrieved by utilizing the query and data mining operations of Vantage Point. Figure 5 represents an example sensor data query result in which the time and the value of each sensor event is printed. Experiments performed with simulated sensor's data have considerably facilitated our work for integration of real physical sensors, which is described next.

```
exampleSimuSensor
TIME AND VALUE
Time:          value:
11:21:31         23
11:21:32         23
11:21:34         21
11:21:39         20
11:21:46         12
11:21:53         22
```

Figure 5. An example SimuContext sensor query result

As a real sensor system we have used the Carerider bed sensor manufactured by Audio Riders (http://www.audioriders.fi). The Carerider bed sensors allow collecting a versatile context data, such as the times an elderly person has got out of the bed during the night, or the respiratory frequency of the elderly. The data produced by the Carerider bed sensors is integrated with VantagePoint context model by uploading a file containing the raw sensor data from Audio Riders' web server, converting the data to a semantic form and storing it as a separate model.

The raw bed sensor data is stored in the Audio Riders' web server as a text file containing the sensor events collected over a period of 24 hours. Every bed sensor event contains such information as time of the event, state of the bed, activity level, breathing signal, estimated breathing frequency and acoustic pressure. Each sensor event constitutes one line of text in the data file and the different measurement values of an event are separated with a comma.

Since the bed sensor provides numerous of events per every minute, the data file storing the raw sensor data is extremely large containing thousands of lines of text. To keep the required computer resources at a manageable level, the amount of data must be reduced before the sensor events are converted into a semantic form. The data extraction is carried out by selecting just one sensor event per each minute, which can be considered as an adequate accuracy for the purposes of VantagePoint. Additionally, VantagePoint removes the lines where the "state of bed" measurement value is "0", because there is no point to semantically store those sensor events when the bed is empty. However, an exception to this rule is the times when the person gets out of the bed but returns shortly afterwards because this kind of data provide valuable information about the possible sleeping disorders of the person.

Once, the noteworthy sensor events are extracted from the data, VantagePoint stores the event information line by line into a semantic model. Each sensor event is given a unique serial number and the measurement values are stored as property values of the events. Finally, the sensor data model is attached to a bed instance held by a VantagePoint context model and the data can be accessed through queries. The results of the queries executed against the bed sensor data model can also be utilized when creating informative diagrams as can be seen in Figure 6. The middle side of the figure shows a part of the original query results and on the right it is shown the created diagram. The visualization of the bed instance holding the bed sensor data is represented on the left side of the Figure 6.

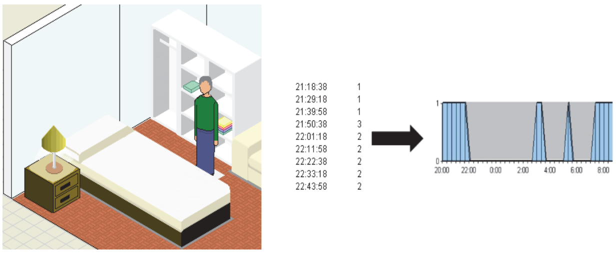

Figure 6. Query results and a created diagram

In order to semantically store different kind of sensor data, a new ontology level taxonomy was needed. The taxonomy for semantically storing sensor data is sketched in Figure 7.

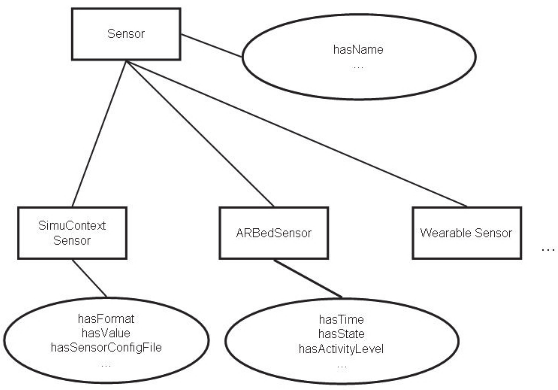

Figure 7. The sensor taxonomy

As presented in Figure 7, the sensor taxonomy contains the ‘Sensor’ main class and one sub class for each sensor type. The ‘Sensor’ class holds properties that are common to all sensor types and additionally, each sub class holds its own sensor type specific properties. For example, the ‘hasName’ property is common to all sensor types, whereas the ‘hasSensorConfigFile’ property is a ‘SimuContext’ sensor specific property. The sensor taxonomy is linked to the VantagePoint context taxonomy by defining the ‘Sensor’ class as a subclass of the ‘Item’ class.

In the AmIE, special touch screens are delivered to a group of test elderly people, who are expected to answer daily to the self-assessment questions shown on the screens. The questions are related to various aspects of aged adult life such as independence, safety, loneliness, etc. The daily questions can be utilized to assess the current state of the elderly. By analyzing the history of such answers some supportive actions towards the better quality of life for elderly adult is made. The information collected from bed sensors, questionnaires and other means available in the future can be utilized by elderly itself, relatives and care givers to obtain quick comprehensive view about how elderly is doing day by day. The state can be visualized in VantagePoint with certain status symbols, as presented for instance in Figure 8.

Figure 8. The state of mind – symbolic indication

VantagePoint supports the storage of the query answers as well as the welfare profiles by allowing its integration with the context models. The integration can be carried out by uploading the self assessment answers from a web server and then attaching them to a persons held by a VantagePoint context model. Similarly, other information such as preferences, agenda, personal data, etc. can be linked to a VantagePoint person, thus increasing the amount of information provided by the context model and the visualization. The ‘Person’ class is integrated to the VantagePoint context taxonomy by defining it as a subclass of the ‘Item’ class.

Moreover the recent trends in well-being, lifestyle and wellness monitoring domain have brought to market the addition types of information-rich services relied on measurements associated with quality of life (daily activity measurements, calories estimation, etc.). Part of this information is stored in personal devices, part may go to the internet servers associated with service provider and part eventually might stay home to be reviewed later or compared for example with achievements of other family members leveraging visualization means supported by VantagePoint.

To make our solution interoperable and easy deployable Vantage Point has been integrated as a bundle to OSGi service platform (see Figure 9). Utilizing OSGi interfaces and Context Broker open source developments [15], external client application is able to receive events using Web Service eventing mechanisms and execute queries supported by SPARQL query language [12] and reasoning capabilities offered by Jena framework, against the information models held by VantagePoint. The events can be initiated by any changes taken place in the information models held by VantagePoint such as exceed of threshold values in case of sensor's measurement, due expire of warranty of home appliances or continues unsteadiness in elderly adult mood. Hereby the information held by VantagePoint can be dynamically shared on demand of services and end-user applications running in home and beyond.

The described tool prototype is in the stage of developments and improvements. More information on VantagePoint (online tutorial, example source code, etc) can be downloaded from [14].

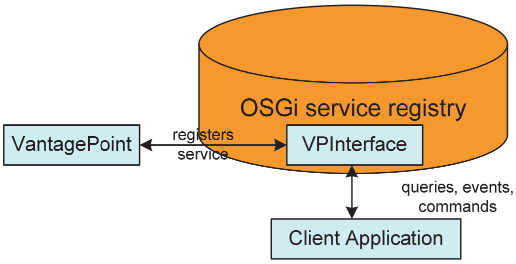

Figure 9. VantagePoint integrated to OSGi service platform

IV. CONCLUSION

This paper has presented the approach that supports the integration and interactive visualization of diverse heterogeneous home data. We believe that user interfaces introduced by VantagePoint tool will attract and inspire home occupants to supervise own home. The capabilities of the tool are easily extendable and customizable. VantagePoint has a basic library of icons representing devices, furniture, persons, etc. These libraries are stored in text files, which contain the URLs of the icon files or PNG images and description of the icons. More PNG icons representing home appliances, furniture or other aspects of interior decoration can be easily drawn using available open source tool (e.g. http://www.paint.net/) and imported to VantagePoint.

The tool has been offered for testing to researchers within VTT and also to partners within AmIE project consortium. The feedback was very positive. Especially the possibility to model own apartments introducing rooms, home appliances and other details of living environment found being very attractive. The tool has been also demonstrated in "Good Age" Expo 2008 [23]. The main audience was elderly adults, their relatives, care givers and industrial representatives manufacturing the products for elderly. As expected the feedback was heterogeneous, more positive from visitors which are skilled in technology, daily using Internet, sometimes Skype and more cautious from other group that generally is not comfortable with technology. However all has acknowledged that tool is interesting as a solution for the smart home of the future and most of visitors has admitted that they would like to have something similar in particular to maintain own house history (keep digital maintenance manual with maintenance instructions, history of purchase and repair, etc.).

As for the future work, we would like to improve the semantic contextual models on which VantagePoint is built. More expressible ontological models will allow for better reasoning on home information, hereby facilitating comparison of data histories and empowering more sophisticated decisions. With wide spread usage and generalization of Internet, other interesting direction is to make VantagePoint more compatible with open Internet standards. This way more useful online information can be imported to VantagePoint environment.

ACKNOWLEDGMENT

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PII

TOWARDS THE USER CONFIDENCE IN SENSOR-RICH INTERACTIVE APPLICATION SCENARIOS

by

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Towards the user confidence in sensor-rich interactive application environment

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ABSTRACT
The recent advances in sensor-rich, ambient computing environmets have led to a situation in which ordinary users may express negative reactions when they feel that their behaviour is being monitored and analysed by technological systems which they do not understand. Cooking guide is an example application that is heavily depended on dynamic context information and adapts its behavior according to the context data. The VisuMonitor approach, described in this study, supports the users of Cooking Guide by providing visualization views that show the proceeding of cooking processes and also explains the functionality and behavior of the system during different cooking activities, thus improving user awareness, technology acceptance and user education. VisuMonitor utilizes semantic technologies in the modeling of workflows, which facilitates data integration and enables more efficient work progress monitoring and visualization.

ACM Classification Keywords
H.1.2 User/Machine Systems: Human factors.

Author keywords
Context awareness, proactive knowledge, sensors, user education, semantic technologies, user education, data visualization

General Terms
Design, Human factors

1. INTRODUCTION
When evaluating the ideas of sensor-rich, ambient computing environments to ordinary users, non-technical people, in particular, express anxiety when they find themselves in situations, where they feel that their behaviour is being monitored and analysed by technological systems which they do not understand [1]. Such negative reaction to applications which use sensing technology sets a challenge which needs to be addressed. Technology must be regarded as helpful rather than threatening. We believe that if users perceive themselves to understand and to have control over their personal application, they will be more likely to trust applications which use sensing data. Accordingly a knowledge-based system should be able to explain its reasoning, and rules used to justify its conclusions to be accepted by users.

Cooking guide is an example application that is heavily depended on dynamic context information [17]. The Cooking Guide may run in a touch-screen device, for example, and it helps the user during meal preparation by providing detailed, step-by-step explanations. Cooking Guide adapts its behavior according to the context information (e.g. available smart appliances augmented by various sensors, output devices, and user's cooking experience) thus each step can be potentially performed in a different way. Cooking guide is a true effort towards the contextual rich dynamic proactive knowledge-based application. Proactive knowledge base is built from the sensors augmenting the objects in use, surrounding devices and user profiles. Sophisticated data mining algorithms, rule based mechanisms and user model learning techniques facilitate contextual awareness and adaptability towards the assistance and end user ambient support.

The importance of explanation interfaces in providing system transparency and thus increasing user acceptance has been well recognized early in a number of fields such as expert systems [2], intelligent tutoring systems [3], office documents user assistance systems [18], data exploration systems [4], and recommendation systems [5][6][7]. In relation to ubicomp environment, the necessity to support the features that aim at supporting user acceptance by making system's reasoning process visible and insight of the system comprehendible has been acknowledged only recently [1][8][9], while prototyping of such feature is still in its infancy. For our knowledge only work by K.Cheverst [9] has practically addressed the transparency and comprehensibility of the system leveraging the power of explanation user interfaces. There the Intelligent Office System can learn a given user situation to use the inferred rules and support appropriate proactive behaviour such as e.g. turning on/off the fun or opening/closing window under appropriate conditions. On the same time, the system enables the user to explicitly scrutinise and override the 'if-then' rules held in user model. If the user wishes to enquire why the system is performed in a certain way, the appropriate button can be pressed in order to view a window such as the one shown in Figure 1.

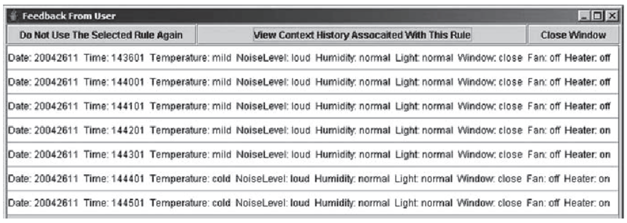

Figure 1. Scrutinising the rules behind the prompt me text

However manually acquired textual explanations may not be always sufficient especially in the cases where the context of the application and user is rapidly varying such as in cooking which is a creative process with continuously changing cooking situation, appliances in use and products features. This sets the additional challenges on the design of the user interface. Moreover, the purpose of the system plays an important role in defying of respective elements that influence system acceptance. When interacting with work and task-oriented systems, the perceived usefulness is more important. In contrast when interacting with hedonic systems that are aimed at fun and pleasure (as cooking guide mostly does) the perceived enjoyment is more desirable in achieving user acceptance [10].

2. VISUALIZATION

Looking for the means to fulfil the above discussed requirements, we believe that visualization based aids which are intuitive and easily customizable, may help the user to link the complex contextual world of physical services residing in the environment, reasoning of the system and human mind. Visualization of data makes it possible to obtain insight into these data in an efficient and effective way, thanks to the unique capabilities of the human visual system, which enables us to detect interesting features and patterns in a short time [11]. In particular with recent advances in computer graphics, visualization is able to benefit the sense of wonder connected with the application presenting the content of the data in a completely innovative and quickly comprehendible form.

Currently existing approaches to visualise the rules of the system are targeting mainly application developers [12][19] or data exploitation professionals [13][14][15][16]. Accordingly common for the developed techniques is that they rather support the categorization, browsing and management of potentially complex rule bases, while the ground to the world of physical devices and context attractiveness, fast assimilation and intuitive visualization important for non-technical end user are left beyond.

3. VISUMONITOR – TOWARDS BETTER USER AWARENESS

In this position paper we present a visual monitoring approach – VisuMonitor, which is currently under development. VisuMonitor is directed for the end-users of different context-aware applications and aims towards a better user awareness, technology acceptance and user educating. The approach enhances the sharing of knowledge by integrating information from multiple, heterogeneous sources and providing interactive views to this data. To enable the integration of heterogeneous data sources, VisuMonitor utilizes semantic technologies and especially ontologies that facilitate shared and common understanding of knowledge domain and are able to describe explicitly the content and semantics of heterogeneous data sources to support integration, processing and further new knowledge discovering tasks. The utilization of semantic technologies provides also an intelligent way to define and use rules that guide the behavior of the application.

The use of semantic technologies is especially pertinent with such applications as the VisuMonitor where complex and heterogeneous data is gathered from multiple sources and it has to be presented to the users in a comprehensive way. The annotation of the data using ontologies and concept taxonomies will allow users to better perceive the relationships between different concepts. Additionally, by utilizing reasoning mechanisms provided by semantic technologies, the data can be better clustered and targeted to the particular users.

VisuMonitor supports the users of Cooking Guide in two ways: showing practical information related to the cooking process itself (the proceeding of the cooking process from one step to another, the information provided by different sensors, the usage of different devices etc.) and providing explanations related to the functionality and behavior of the cooking guide system (for example why the cooking guide application decided to change from speech to textual guidance in some point of the cooking process etc.). VisuMonitor may also educate the user by explaining why the particular recipe/ingredients are recommended e.g. due health reasons, diseases, dietary, recent blood test, etc.

Different cooking processes executed with Cooking Guide are modeled as workflow descriptions. Cooking Guide is tightly integrated with a Workflow engine tool, which manages the workflows that are executed in cooking processes. The executable workflows are described with an XML-based serialization format known as XPDL [20] (XML Process Definition Language). XPDL is a common format supported by a number of editing tools and process execution engines. XPDL workflow models are standardized representations of one or more workflows. The workflow engine plans, checks and manages the execution and states of workflows. If an activity is finished, it is e.g. responsible for checking outgoing conditions of transitions and deciding if the transitions should be activated or not. Workflow engine utilizes also context information extensively. Besides of information source, the engine uses context data to adapt to the situation, to trigger activity transitions and to influence the control flow.

VisuMonitor communicates with Workflow engine to retrieve the necessary information needed for workflow visualizations. In addition to static and dynamic workflow representations, VisuMonitor provides also other workflow related information to the users. It may show, for example, the different resources needed to complete a workflow activity or information related to functionality and behavior of the cooking guide system. By integrating the data acquired from Workflow engine and Cooking Guide, VisuMonitor is able to produce a global view of a cooking process.

3.1 Compositional structure

The compositional structure of the VisuMonitor infrastructure is shown in Figure 2.

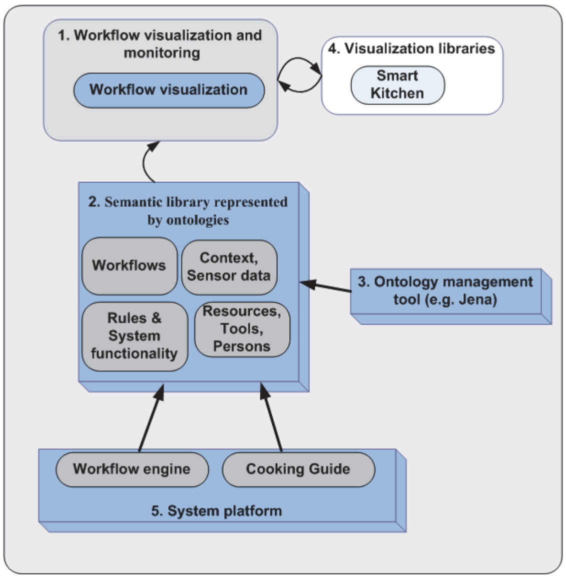

Figure 2. The compositional structure

(1) - Workflow visualization and monitoring, which is a core of the tool. This component provides mechanisms for visualizing workflows and other related information.
(2) - Semantic library represented by ontologies, which will contain the workflow related knowledge base. This component contains semantically modelled workflow descriptions that are visualized with the tool. It may also contain other semantically modelled information, such as context and sensor data, rules and other system functionality data and information about different resources that are related to workflows.
(3) - Ontology management tools, which allow to query and update ontology instances. Some existing open source software like Jena and OWL-API reasoners can be used for this purpose
(4) - Visualization libraries containing domain specific 3D icons that are used in workflow visualizations.
(5) - System platform, which provides the necessary data for workflow visualization. For example, the workflow engine provides static information about workflows and the Cooking guide allows to query such information as the rules applied in the user interface adaptations.

Device/hardware level: from laptop/PC to light device like PDA/smart phone.

3.2 Dynamic structure

While compositional structure provides the static layout of the workflow monitoring architecture, the sequence diagram presented in Figure 3 highlights the way on how different components dynamically interact.

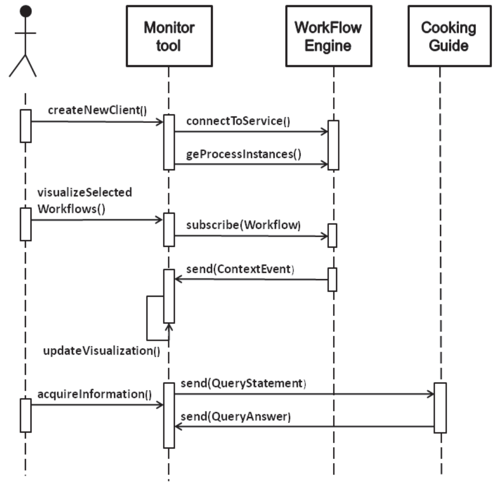

Figure 3. The dynamic workflow visualization

According to the sequence diagram above, the user may first create a client in order to start monitoring workflows. VisuMonitor connects to Workflow engine and retrieves the workflows that are currently hosted by the engine. The user may then select the workflows that he/she wants to visualize and monitor. Subsequently, the monitor communicates with Workflow engine and subscribes as a listener to the selected workflows. As a result, Workflow engine notifies the monitor each time something noticeable happens in the execution of the selected workflows (i.e. a transition from one activity to another or some exception/anomaly occurs during the execution). Each time VisuMonitor receives a change notification it updates the visualization view accordingly. VisuMonitor may also query some additional, workflow related information from the Cooking Guide application. The monitor may acquire, for example, such information as the logical rules applied in a certain cooking activity.

3.3 Semantic data integration

As earlier discussed, VisuMonitor utilizes semantic technologies to provide visually rich and informative workflow representations to the users. For example, by using well defined ontology vocabularies and taxonomic hierarchies data gathered from heterogeneous sources can be better integrated and semantically modeled. For example, when the monitor tool receives non-semantic workflow descriptions, it saves them semantically and annotates the data with descriptive metadata. Next VisuMonitor stores the workflow activities into an RDF data model and finally visualizes the workflows. Whenever additional information is queried from Cooking Guide application, it can be stored into the same RDF model and linked to the appropriate activities of the workflow.

The semantic modeling of workflows has many potential benefits. For example, more comprehensive diagnostics information about the work processes can be produced by discovering the hidden relationships and patterns that may exist in the data. The diagnostics information can include historical, real-time and predictive data. Additionally, the utilization of different reasoning mechanisms may lead to proactive action recommendations, which in turn enable more efficient fault prevention. Finally, the semantic modeling of data enables more efficient work progress monitoring and visualization. An excerpt from an RDF-description of semantically stored workflow data is presented in Figure 4.

```
<rdf:Description rdf:about="http://owl-ontologies.com/SmartKitchen.owl#ProcessInstanceId3">
  <VisuMonitor:activityDefinitionId rdf:datatype="http://www.w3.org/2001/XMLSchema#string">makeCoffe
  </VisuMonitor:activityDefinitionId>
  <VisuMonitor:activityName rdf:datatype="http://www.w3.org/2001/XMLSchema#string">Make Coffee
  </VisuMonitor:activityName>
  <VisuMonitor:priority rdf:datatype="http://www.w3.org/2001/XMLSchema#int">5</VisuMonitor:priority>
  <VisuMonitor:state>CLOSED.COMPLETED</VisuMonitor:state>
```

Figure 4. Example RDF workflow data description

Each of the activities contained by a workflow is defined as an individual, which has certain property and value descriptions. For example, the activity described above has a property ‘activityDefinitionId’ with value ‘makeCoffee’ and a property ‘state’ with value ‘CLOSED.COMPLETED’.

3.4 UI design mock-ups

VisuMonitor tool is currently in a design phase and different specifications of the tool are being created. Since visualization and graphical user interface form such an important part of the approach several user interface mock-ups were decided to be created and evaluated before the actual implementation work is started. The purpose of the initial evaluations is to make sure that user perceive the created views and explanation dialogs as informative and comprehensible.

UI design mock-up presented in Figure 5 shows an overall view of the cooking process, in which the proceeding of the workflow from one step to another is illustrated. The already finished activities are depicted with blue boxes, the current step of the cooking process is emphasized with red color and the green boxes represent the activities that have not yet been started. The user is able to acquire more detailed information about different activities by clicking the boxes representing the different steps. The purpose of this kind of overall view is to enhance the general comprehension of cooking processes.

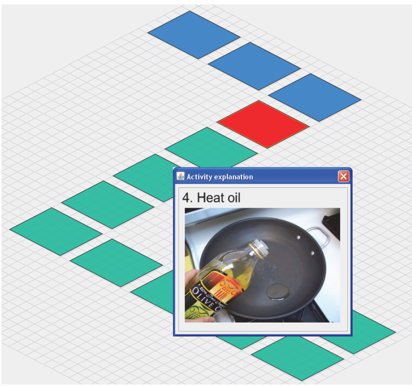

Figure 5. A workflow visualization mock-up

As earlier discussed, a knowledge-based system should be able to explain its reasoning and rules to justify its conclusions. VisuMonitor addresses this requirement by providing illustrative graphical explanations that makes the behavior of the cooking guide system more transparent. VisuMonitor provides explanations, for example, about the logical rules that guide the functionality of the Cooking Guide system during a certain cooking activity. As an example, a visualization presented in Figure 6 explains one of the rules that automatically turn the Cooking Guide’s audio features off if music is detected during the last 20 seconds.

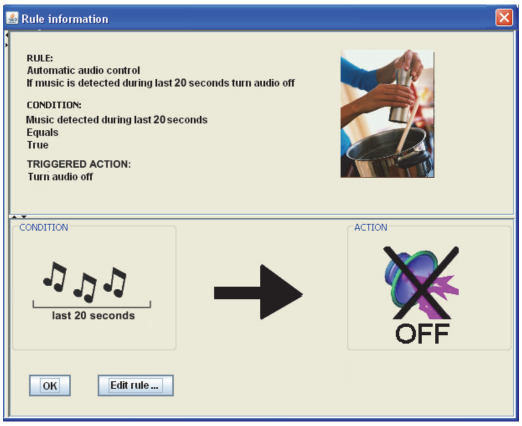

Figure 6. A rule visualization mock-up

Although VisuMonitor is still on a design phase some of the initial user interface mock-ups have been already evaluated in a user study performed for the Cooking Guide prototype [17]. The results proved that VisuMonitor enhances the understanding of application behavior and makes the functionality of Cooking Guide more appreciable for the user.

4. CONCLUSION AND FUTURE WORK

This paper has presented the VisuMonitor approach, which addresses the problem of complex sensor-rich, ambient computing environments causing negative reactions for ordinary users, as they feel they do not have control over their personal applications. VisuMonitor enhances the understanding of application behavior by applying interactive visualization techniques that enable users to observe, manipulate, search, navigate, explore, discover and filter data far more rapidly and far more effectively.

VisuMonitor is tightly coupled with the Cooking Guide application, which provides step-by-step explanations for meal preparation and adapts its behavior according to the context information. VisuMonitor supports the users of Cooking Guide by providing visualization views that show the proceeding of the cooking process from one step to another and also explains the functionality and behavior of the system during different cooking activities. By utilizing different visualization methodologies it aims at improving user awareness, technology acceptance and user education.

An important feature of chosen visualization approach is that it semantically integrates heterogeneous data gathered from different sources. In this way all the workflow related data can be modeled and stored in a similar and structured way. The semantic representation of data facilitates also the discovering of hidden relationships that may exist in the data.

The development of VisuMonitor is currently in its initial stage. The work will continue by analyzing thoroughly the results gained from the evaluation and applying this data in the implementation phase. The construction process will be iterative by its nature and after each design and implementation cycle the approach will be evaluated with the end-users.

Although VisuMonitor is currently developed in a close cooperation with the Cooking Guide application, we are looking for more generic domain independent way to support application users. Different application domain may set an additional research challenge, for example on the visualization aspects like various visualization types might be used depends on the problem domain and also on application features to be monitored and visualized. Additionally, the workflows describing semantic models will be improved by developing the data integration methods and using more sophisticated reasoning capabilities

5. ACKNOWLEDGMENTS

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PIII

MONITORING AND VISUALIZATION APPROACH FOR COLLABORATION PRODUCTION LINE ENVIRONMENTS: A CASE STUDY IN AIRCRAFT ASSEMBLY

by

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Monitoring and Visualisation Approach for Collaboration Production Line Environments: A Case Study in Aircraft Assembly

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Abstract

In this paper, the SPMonitor tool, which is designed to monitor and visualise run-time execution of productive processes, is proposed. SPMonitor enables the dynamic visualisation and monitoring of workflows running in a system. It displays versatile information about currently executed workflows, thus providing a better understanding of processes and the general functionality of the domain. Moreover, SPMonitor enhances cooperation between different stakeholders by offering extensive communication and problem-solving features that allow the actors concerned to react more efficiently to different anomalies that may occur during a workflow execution. The ideas discussed are validated through a real-life case study related to aircraft assembly lines.

Keywords: Collaboration, Productive Lines, Workflow, Monitoring, Visualisation.

1. INTRODUCTION

The field of computer-supported collaboration work is often associated with office work. However, industrial production lines such as products assembly lines are highly relevant as a case for this research field. Several issues are involved considering the complexity of products manufactured:

- In such processes, various teams with different areas of technical expertise are involved in activities to be performed synchronously. These activities are not always sequential.
- There is an increasing complexity of subsystems to assemble, along with the fact that supply components come from various industry parties and players.
- One activity in the process may influence another, therefore the coordination is required.
- There is heterogeneous information all over the shop floor and interdependencies exist within the information spaces.
- There are external factors impacting operational status, such as unavailable or multifunctional equipment, delay in supplier components or changes in the human resources involved.

In addition, tight deadlines and a reduction in the time-to-market place additional pressure on the organisation and monitoring of working processes towards their productivity and the quality of the final product.

The design and development of modelling and analytical techniques of the production lines was the subject of extensive study in the past. The use of commercial digital mock-up systems (DMU) enabling different visual qualities and functions are becoming more common [1][2][3]. However, effective real-time progress monitoring tools supporting DMUs are still immature.

The complexity of modern production lines and the dynamic nature of the domain make it difficult to maintain the ‘As-Planned’ progress during the actual execution (e.g. discrepancies and frequent changes). This results in schedule and cost overruns, which accordingly call for the efficient monitoring and coordinating interfaces with the production process, which is able to provide a real-time view of the current state of processes and relevant attributes (‘As-Is’ view).

Existing coordination solutions developed and reported in the literature so far are mainly based on public interactive displays. The andon system [4] made famous by Toyota is simply a way of reporting the occurrence of a problem on the assembly line (‘andon’ is the Japanese for ‘signal’). In case of a problem, the operator pulls an alarm cord and an electronic board is activated. Early projects, such as LiveBoard [5], focused on supporting collaborative activities through large electronic whiteboards using novel interaction techniques. Later on, this work was extended in recent projects by embedding several interconnected displays in the environment to support more complex collaboration activities, including Trauma’s center Whiteboard [6] iLand [7] and iRoom [8]. From an application point of view, the closest to our research is a study presented by [9] targeting user acceptance issues in the environment composed of large public displays to facilitate the collaborative process in the aircraft final assembly lines in Toulouse. There are also other applications that have exploited large displays to make information on activities available to a community of users.

These systems are developed with the objective of supporting a broad spectrum of group activities, creating a common information space and providing the background awareness on activities that a number of various groups/teams are involved in and tasks that have been accomplished. However, for a productive assembly project, as-built progress or DMU should be constantly monitored and compared with as-planned assembly progress, and real-time prompt corrective actions should be taken in case of observational discrepancies. Current tools such as graphs, charts and photos may not facilitate the communication of progress and ensure corrective action is taken clearly and quickly enough. More advanced means aiming at anticipating problems like overlaps of assembly parts and proposing corrective actions in an intuitive and promptly intelligible way are still lacking.

Based on the aspects discussed above and through the exploitation of the close cooperation with the EADS R&D team in the European Smart Products project [10], this paper presents a novel approach to support the collaboration of various actors involved in the processes related to production line environments.

Leveraging recent advances in semantic technologies, 3D visualisation techniques and contextual workflow modelling mechanisms, SPMonitor provides intuitive and convenient visual aids to support various actors involved in overall processes running on industrial production lines. By managing the interdependencies between numerous activities running concurrently, it aims to provide support for the combining, storage and distribution of various statuses, scheduling information, tasks, the usage of resources and tools, and updates providing contextual views to operators, support teams and managers responsible for the overall processes on the line. The combination of interaction means and interface elements to run-time environment and DMU facilitate the ability of the tool to quickly sort and display the performance metrics and deviations, possible unexpected events and anomalies in order to highlight the high priority requirements and actions required for recovering from errors and assembling resources.

In addition, from a scientific point of view, this research contributes with the novel approach of semantically annotated contextual workflow-based production process description. Semantically described workflows provide powerful reasoning potential to align information spaces of productive lines and enable richer visualisations showing comprehensive data in a single view. The ontologies used to describe workflows, environmental features and sensory perception devices can be flexibly extended. With new plug-in domain-specific ontologies, the tool can support additional application domains.

Moreover, the visualisation layer of semantically defined workflow descriptions supporting real-time progress monitoring is proposed. Various contextual views empowered by 3D functional graphic elements provide the value for the coordination and control of production lines. The visualisation libraries can be extended with domain-specific needs.

This paper is divided into six sections. Section 2 presents the background of the application domain for our study and the most important requirements that guided the development of the SPMonitor. Section 3 details the design and implementation of the tool. The run-time execution of SPMonitor and experiments that were accomplished to validate the prototype are described in Section 4. Section 5 provides the initial evaluation results performed by researchers and domain experts to measure the usability and perceived usefulness of the tool. Finally, Section 6 presents the conclusions drawn from the research project.

2. CONTEXT AND REQUIREMENTS

On an aeronautical final assembly line, the aircraft goes through several stages before completion. The process is often not sequential: several operator teams can be involved at the assembly station. Apart from operators performing assembly tasks, there are also support teams and a manager. The support teams help operators to solve operational problems and verify the technical issues, deal with logistics and ensure that the necessary tools are available for operators. The manager is responsible for the overall process of assembly and is also able to take action in cases where discrepancies are detected. Paper-based coordination between various actors is still used on the lines. Operators facing a problem or needing to validate an operation have to walk over to the support offices, write a report and verbally notify the appropriate support person. This all takes time.

In our context, the realistic scenario provided by EADS for research purposes involves two operators who have received a work order to tighten two electric harnesses onto an aircraft panel. Both operators work simultaneously on the same work order, which may contain several sub-tasks. The operators are also equipped with tools, a nomadic device and a smart tool (e.g. a smart rivet gun, a smart glue gun or a screwdriver). The nomadic device guides the worker through the workflow and the smart tool is used to tighten assemblies. The scenario also includes a support team that monitors the assembly procedure remotely and reacts in case of unexpected events during the process, and a station manager who is in charge of the overall organisation of the assembly line. More information about the background to the scenario can be found in [11] [12].

The main purpose of SPMonitor is to support cooperation between different actors in the scenario. First of all it should provide better understanding about work processes by representing an up-to-date visualisation of the current state of the assembly process. Besides visualising work processes, SPMonitor should be able to show illustratively the possible anomalies that may occur during a workflow execution and help the support team to react more efficiently to the problems. Moreover, SPMonitor is supposed to be used as a collaborative tool to exchange information between operators and the support team when resolving anomalies. Finally, SPMonitor can be utilised in the subsequent diagnosis, in which the support team and the station manager analyse the workflow performance data and any possible anomalies in cooperation.

3. DESIGN AND IMPLEMENTATION

Based on the context and requirements discussed previously, an approach that supports the collaborative visualisation of assembly processes was built. SPMonitor contains three main building blocks: a workflow management system, communication middleware and monitor software. The role of the workflow management system is to manage and execute processes and provide the necessary information for external applications. The communication middleware intermediates, either remotely or locally, between data from different components, and finally, the monitor software implements functionalities required for workflow monitoring. Figure 1 represents the compositional structure in more detail.

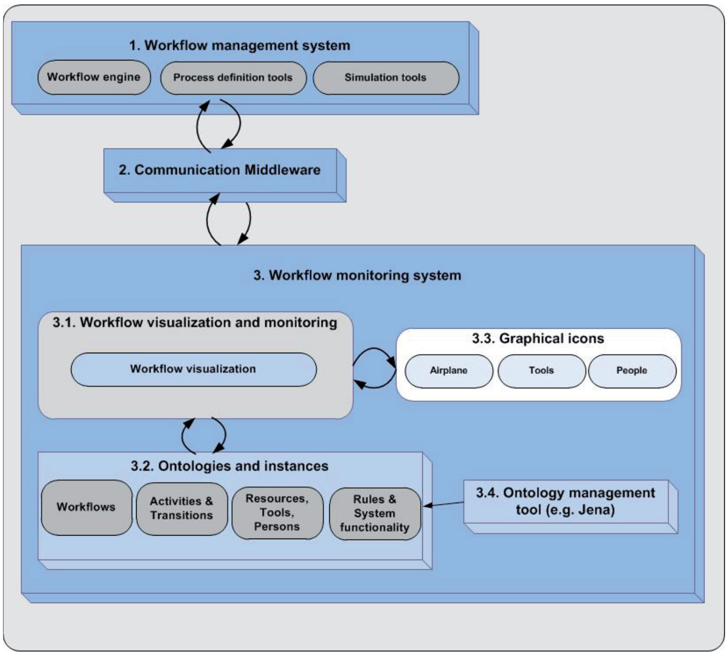

FIGURE 1: FMC block diagram of the SPMonitor components

The different components are described below in more detail:

- **Workflow management system** contains software tools for designing, defining and executing workflows. Additionally, it provides the necessary data for workflow monitoring using publish/subscribe mechanisms, for example.
- **Communication middleware (API)** acts as an intermediary between workflow management and monitoring systems. Moreover, it provides a means to remotely discover different components in the line system. Mundocore middleware [17] is used to provide the communication infrastructure for the information exchange in the line.
- The **workflow monitoring system** realises the different functionalities needed for semantically modelling and visualising different processes and reacting to anomalies. The main parts of the workflow monitoring system:
  - **Workflow visualisation and monitoring** is a core component of the system. It provides mechanisms for visualising workflows and other related information, as well as possible anomalies. Additionally, it implements the different interactive elements needed, for example, for managing anomalies.
    - The **ontologies and instances** component is a semantic library represented by ontologies which contains a workflow-related knowledge base. This component hosts the semantically

modelled workflow descriptions that are visualised with the monitor tool. It may also contain other semantically modelled information, such as rules and data describing different resources that are associated with workflow activities.

- **Graphical Icons** provide visualisation libraries containing domain-specific 3D icons that are used in workflow visualisations
- The **ontology management tool** allows querying and updating ontology instances.

3.1 Semantic Workflow Data Model

One of the requirements that arose in the scenario was enabling the integration of heterogeneous workflow-related information into a single data model, which in turn facilitates more sophisticated data analysis and diagnostics capabilities through automatic reasoning and richer query opportunities, for example. The diverse work process data includes information such as activities, transitions, resources (e.g. people, tools), restrictions (e.g. deadlines, required skill levels) and preconditions. Semantic technologies play an important role in realising this requirement as they allow describing workflow activities, transitions and resources in a semantically rich form, and additionally, they provide powerful reasoning potential [29]. The data fusion capabilities also enrich the visualisations because the integration of data from multiple sources increases the amount of available workflow information, thus leading to more comprehensive visual representations.

As explained above, SPMonitor acquires non-semantic workflow information from a workflow engine and converts it into semantic form. Currently there are several [20][21][22] usually domain dependent approaches that define ontologies for semantically describing workflows. Moreover [19] defines a semantic workflow language OWL-WS (OWL for Workflow and Services) and a specific semantic workflow representation model for describing dynamic work processes that also enable the specification of higher-order workflows.

However, for this study it was decided to design a new workflow ontology that adopts some elements from the existing approaches but is especially adapted and optimised for visualisation and monitoring purposes. This more lightweight and flexible ontology is unencumbered by the burden of providing a means for workflow task processing. On the other hand, the defined ontology structure offers enough expressiveness to allow for the performing of sophisticated diagnosis and analysis operations. Additionally, the workflow ontology is general enough to be able to address various problem domains. The specified ontology was influenced by our earlier work on designing expandable ontologies for facilitating heterogeneous data integration for data mining and visualisation purposes [24].

The ontology specified in this study defines concepts, relationships and attributes needed for describing workflows and other related information. This workflow ontology holds the class and property definitions of the entities that the SPMonitor workflow models are built on. The class hierarchy of the workflow ontology is presented in Figure 2.

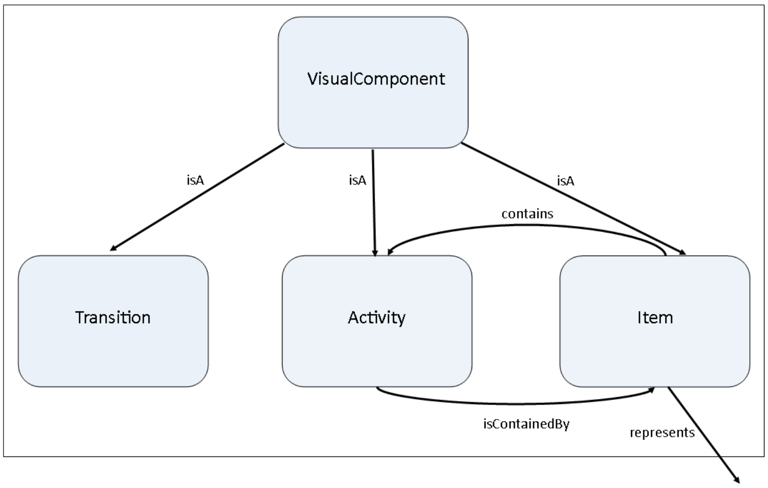

FIGURE 2: Context taxonomy

The main class of the workflow ontology is ‘VisualComponent’, which is divided into three subclasses – ‘Transition’, ‘Activity’ and ‘Item’. The class ‘Transition’ represents transitions that link different activities together. For each transition an ID, a source activity and a destination activity must be determined. Additionally, a transition may have a type property, which describes the type of relationship between source and destination activities. Possible type values for transition are “otherwise”, “condition”, “default exception” and “exception”. The class ‘Activity’ represents different steps or tasks of a workflow. Each activity instance defines its own ID and state values. The possible state values for activities are “not started”, “open - running” and “closed – completed”. Moreover, an activity may hold some additional properties such as resource requirements or time constraints. The third sub-class, ‘Item”, refers to entities that are contained by an activity. A typical item may be an operator that is assigned to a certain activity. Items may also have their own property values describing them in more detail.

SPMonitor forms semantic descriptions of workflows according to the ontology presented above. These models are dynamically updated each time a workflow management system sends an event message informing of activity state changes or anomaly occurrences, for example. The semantic workflow models are saved as OWL [23] files that can be used by other applications or opened with SPMonitor to be visualised or analysed later. Although the presented ontology is quite concise, its true power resides in its expandability. The ontology can be extended by integrating “plug-in” ontologies into it. This can be carried out through sub-classing or mapping concepts together with the ‘owl:sameAs’ statement, for example. With these plug-in ontologies, the tool can be adapted to support multiple different problem domains or integrated with other existing workflow ontology definitions.

3.2 Interactive Visualisation

The support for the enhanced understanding of work processes was released by designing illustrative and transparent workflow visualisation views that give a good overall representation of the data, and also provide the opportunity to acquire more detailed information on demand. Effective visualisation approaches enable humans to observe, manipulate, search, navigate, explore, filter, discover, understand and interact with data rapidly and effectively, to discover hidden patterns [30][31]. Moreover, interactive visualisation allows for the examination of the presentation of data on the fly from different perspectives and angles, helping the end user to understand the results of analysis and information retrieval better [13]. Thus, the different visualisation schemes were implemented to allow users to see various aspects of monitored workflows with different levels of abstraction and to interact extensively with the data being visualised.

The visualisation of workflows in SPMonitor is based on the Model-View-Controller (MVC) framework, which is a widely used architectural approach for interactive applications. The framework is successfully utilised earlier in the interactive visualisation of semantic context data, for example [25]. The Model-View-Controller framework divides functionality between objects involved in maintaining and presenting data to minimise the degree of coupling between the objects [14]. In the Model-View-Controller architecture, objects of different classes take over the operations related to the application domain (the model), the display of the application's state (the view), and the user interaction with the model and the view (the controller) [15].

The modularity of components has enormous benefits, especially when building interactive applications. Isolating functional units from each other as much as possible makes it easier to understand and modify each particular unit, without having to know everything about the other units. This three-way division of an application entails separating the parts that represent the model of the underlying application domain from the way the model is presented to the user and from the way the user interacts with it [15].

SPMonitor presents a novel way of visualising semantically defined workflow descriptions by providing four distinct views to examine models: a general view, a text view, a 2D view and an isometric view. In the following, each of the four views is described in more detail.

- **General view** gives a general picture of the overall situation. It shows the workflows that a currently active in a workflow management system and their current states.
- **TextView** provides a representation of a workflow model as it is written in OWL format. The view allows examining a workflow model in a textual form enabling also to discover the hidden workflow data that cannot be visually represented.
- **2DView** represents activities and transitions of a workflow in a “ground plan” like view. Activities are visualised as squares that are connected by transitions and the colour of the squares indicate the state of different activities. Similarly, the types of transitions are presented using colour codes. The purpose of the 2D view is to provide a better general insight of a workflow. In general, 2D views are considered better for navigating, establishing precise relationships and performing spatial positioning [16][17].
- **Isometric view** builds a visual representation of workflows from an isometric perspective. The visualisation provides a general picture of the monitored workflow and additionally it allows for the integration of varied workflow-related information within a single view perspective. For example, a visualisation of an activity defining an assembly task may include icons that represent the operator that is assigned to that activity or tools that are needed for executing the assembly task.

4. RUN-TIME EXECUTION

During the assembly process where several working processes are running in the background, a support team may examine the situation and select a workflow to be monitored. SPMonitor acquires the necessary information from the workflow management system and forms a semantic model of that workflow. To enable the dynamic monitoring of a selected workflow, the workflow management system notifies SPMonitor of different changes in the workflow execution data. For example, each time a monitored workflow proceeds from one activity to the next, a notification is sent to SPMonitor and the views are updated accordingly. The sequence diagram shown in Figure 3 illustrates the monitoring of workflows with SPMonitor in more detail.

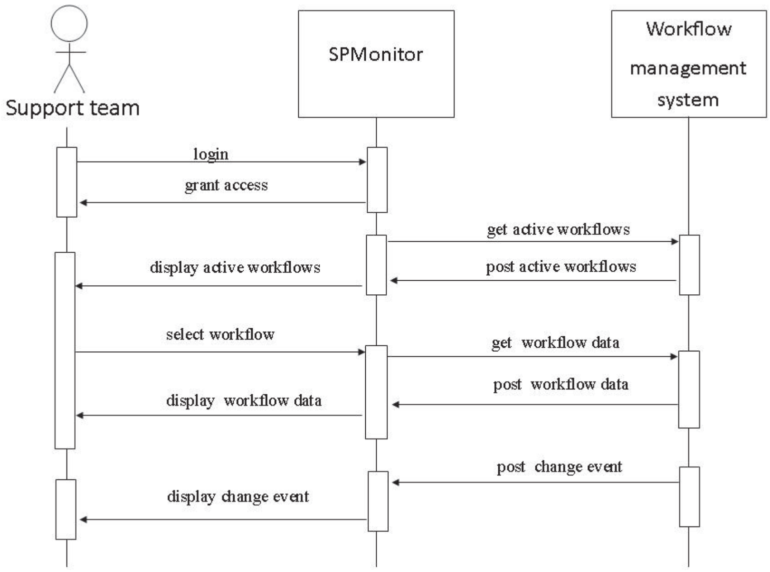

FIGURE 3: A sequence diagram of workflow monitoring

As previously discussed, SPMonitor contains three different views to visualise a single workflow. A graphical representation of the workflow model illustrates the different activities and transitions that are contained in the monitored workflow. The support team has also the opportunity to acquire additional information about a single activity by browsing for it. The opened information dialogue contains such information as work order name, operator performing task, state of activity, and possible sub-flow and sequence order of the selected activity. The status of different activities is indicated with the use of colours. The light blue colour means that the status of an activity is “not started”, a darker blue colour indicates that an activity is currently in the state “open - running” and the darkest blue shade symbolises the “closed – completed” state. Finally, if an activity is red, it means that an anomaly has occurred during the execution of that activity.

The different transitions are also indicated using colours. For example, a conditional transition is represented using yellow and an activity that is only entered in the case of an anomaly is interlinked with a red transition. If a transition does not have a type property, it is coloured grey. Figure 4 represents a screenshot from SPMonitor in which the workflow of the assembly case is visualised. The 2D view is shown in the upper panel and the isometric visualisation is represented in the lower part of the picture. As can be seen, the 2D view provides a more general picture of the monitored workflow, showing all the activities and transitions within a single view, whilst offering zoom in and zoom out functionalities. The isometric view represents a more detailed view of the workflow, populating different activities with icons that represent the operators and tools assigned to those activities.

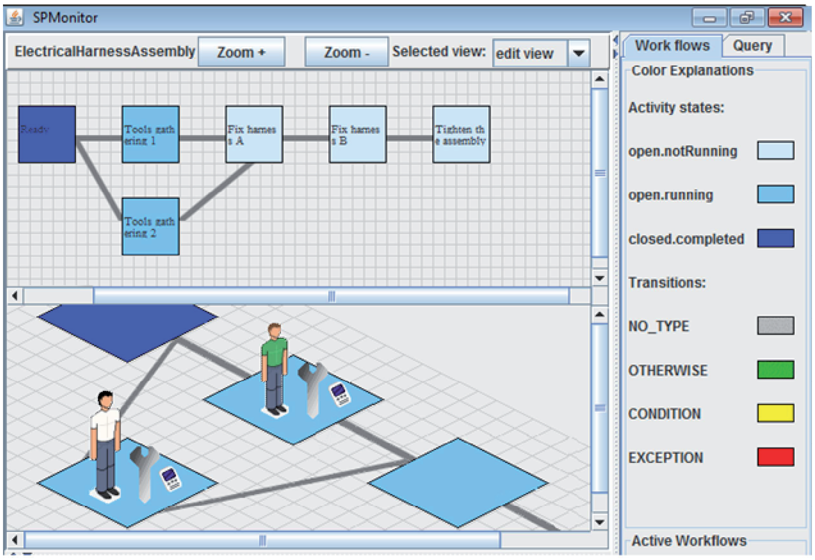

FIGURE 4: Visualisation views representing the monitored workflow

In the domain of aircraft manufacturing, work orders are often so complex that they cannot be expressed with single-level workflows and thus multi-level work processes must be utilised. In multi-level work processes, workflows contain activities that comprise a workflow of their own. These sub-workflows define the tasks that must be performed inside an individual main-workflow activity in order to complete it. Additionally, several operators may be assigned to a single workflow, which demands that activities are performed in parallel. In order to address these challenges, the functionalities of SPMonitor were designed to support the monitoring of workflows that include numerous of sub-workflows and various operators. For example, when a monitored workflow proceeds to an activity that launches a sub-workflow, SPMonitor automatically opens that sub-workflow to be monitored in a currently active visualisation view

4.1 The Management of Unexpected Events

An important part of the EADS scenario is the treatment of an unexpected event during the process. First, SPMonitor must dynamically inform the actors concerned about an occurrence of an anomaly and second, it must provide the means to recover from a problem situation. The sequence diagram presented in Figure 5 illustrates the interaction between SPMonitor and the support team in the scenario.

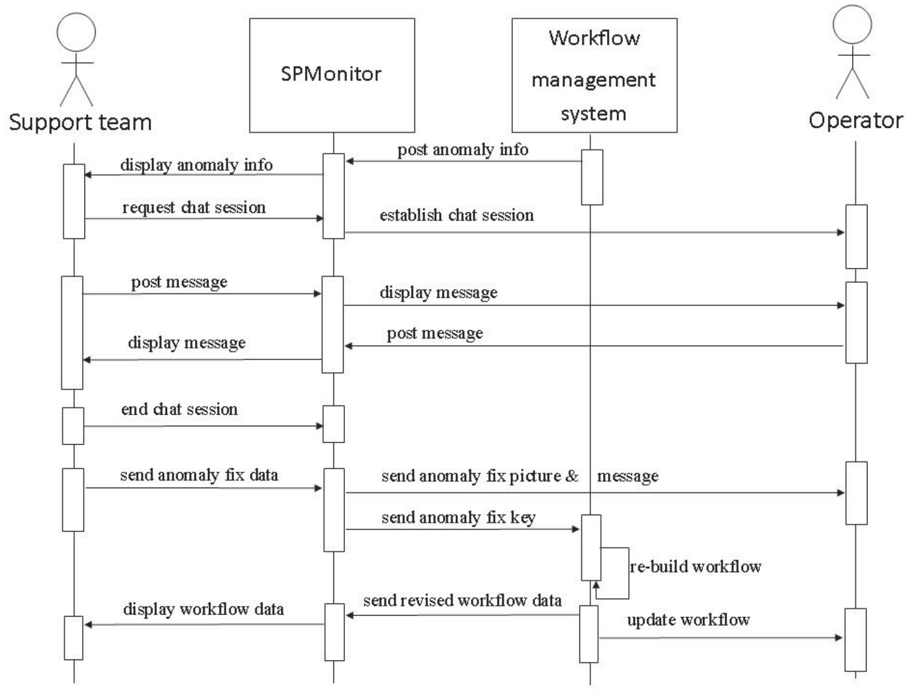

FIGURE 5: The sequence diagram for anomaly management

To facilitate the interaction between various actors involved, SPMonitor defines an interface element that enables the workflow engine to send a notification about unexpected events. The notification contains the necessary information for addressing different problems. Additionally, SPMonitor includes various communication features and problem-solving functionalities that assist users in managing unexpected events. For example, the support team is able to dynamically modify process definitions at run-time.

Any anomalies that occur are usually managed in cooperation with operators and a support team. SPMonitor enhances the cooperative work by disseminating information about anomalies and providing communication mechanisms to exchange data between employees. In the example scenario an operator notices that an earth wire is missing and thus decides to interrupt the procedure as it cannot be finished properly. The operator is also able to describe the problem in more detail by writing an anomaly message using the nomadic device.

In SPMonitor, the anomaly is indicated by representing the involved activity in red and opening an anomaly information dialogue. The anomaly information dialogue contains such necessary details about the unexpected event as the activity in which the anomaly occurred, a descriptive picture and the message that the operator has written. If the support team perceives that the data contained by the anomaly information dialogue is inadequate, it can start a chat session with the operator to acquire more details about the problem. SPMonitor establishes the chat connection with the operator's PDA device by using a communication middleware solution.

Once the support team has enough information about the anomaly, it can decide how to proceed with the task orders. If the support team feels that the assembly process can be completed despite the anomaly, it can informally advise the operator on how to work around the problem and press the 'Proceed' button in the anomaly information dialogue. However, if the unexpected event prevents the workflow from proceeding, the support team can interrupt the workflow by pressing the 'Stop workflow' button. In this case, the support team will usually need to completely redesign the process definition with the workflow management system.

The final option is to dynamically redesign the workflow using the communication capabilities of SPMonitor. In that case, the support team defines a 'fix key' that indicates to the workflow management system how the problem can be resolved in run-time. Besides the fix key, the support team defines a descriptive picture and a textual message that guide the operator in solving the problem. The information is transmitted to the workflow management system that re-directs the descriptive picture and the message to the operator's nomadic device and adds a complementary activity into the workflow. In this case, the new activity is called "Fix earth wire". Subsequently, it notifies SPMonitor of the changes in the workflow so that the monitor visualisation can be updated. The data flows between the operators and the support team is illustrated in Figure 6.

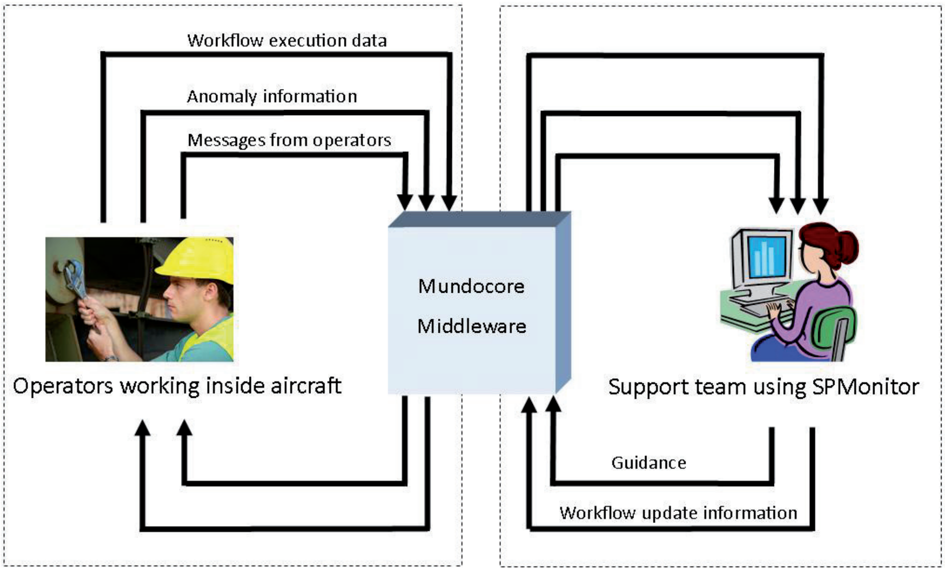

FIGURE 6: Data flows between the operators and the support team

5. EVALUATION

SPMonitor aims at supporting cooperation work by enabling the remote monitoring of workflows proceedings and providing communication mechanisms to exchange information among different actors. The tool also provides interactive means to acquire additional information about workflow activities and react to unexpected events during processes. Due to the purpose of the tool, we think that usability and the perceived usefulness are the most important characteristics to be evaluated. Apart from evaluating the usability of the tool, we were interested in obtaining evaluation results regarding the acceptance of the SPMonitor as new technology in the aircraft assembly processes.

According to the Technology Acceptance Model (TAM) [26], a number of factors influence users' decisions about how and when they will use new technology. These are 'perceived usefulness' defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" and 'perceived ease-of-use' defined as "the degree to which a person believes that using a particular system would be free from effort". A six-indicator measurement for the usefulness of technology using the example of email was introduced by Davis. In our evaluation we reused some of these metrics.

For the evaluation we used an empirical usability testing approach, which relied mainly on the coaching method, thinking aloud protocol [27] and post-test questionnaires constructed to mirror the usability measurement discussed above, and secondly a focus group method [28]. The focus group comprised seven researchers with heterogeneous experience in workflow management, semantic knowledge modelling, services and support tools.

The practical implementation of the evaluation followed the aircraft manufacturing scenario, in which the electrical assembly procedure is presented from the planning stage to its certification, including the treatment of an unexpected event during the process. For the empirical usability testing, the researchers, usability specialists and domain experts from EADS were invited to participate. The test was started by clarifying the goals, objectives and intended purpose of use of SPMonitor. Instructions for completing the test tasks were also given on paper so those involved in the test could familiarise themselves with the tasks before starting the test. After the introduction of software, the participants were asked to perform the aircraft manufacturing scenario related tasks with SPMonitor.

First of all, the empirical usability testing gave us confirmation that SPMonitor is considered a useful tool by its end users and that the chosen visualisation techniques are suitable for monitoring workflows. In addition, the provided interaction functionalities were seen as adequate by the test participants. For example, a test participant from EADS estimated that the chat feature is sufficient for resolving 90% of the encountered problems. At the same time, usability testing revealed some ideas on how to improve the tool. For example, the distinction between main workflows and sub-workflows should be clearer in the visualisations. The activities that contain sub-workflows should be represented more explicitly and more general views representing hierarchy levels of different workflows should be provided. Another feature that received some criticism was the anomaly information dialogue. It was suggested that the dialogue should provide more detailed information about the unexpected event. Finally, participants felt that the graphical user interface should indicate more clearly those activities which were being performed in parallel.

In the final phase of the test process, the test participants were asked to fill out a questionnaire, which included questions related to the perceived ease-of-use and usefulness of the tool. The questionnaire contained both questions on a Likert scale from 1-5 and open questions requiring a written answer. Figure 7 presents the average response levels with numerical answers.

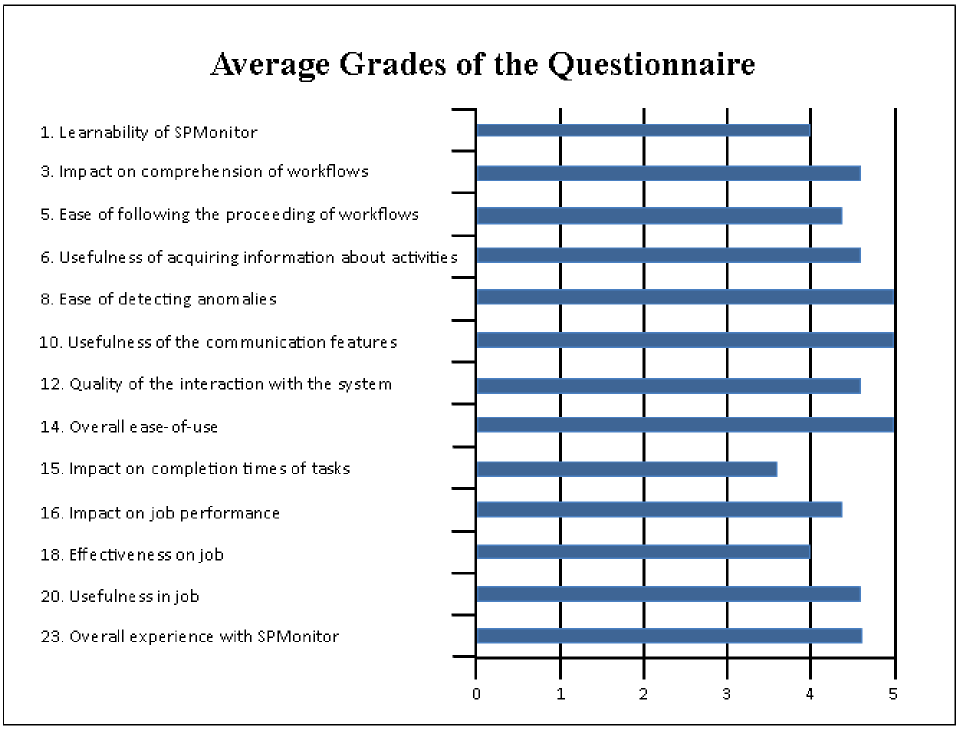

FIGURE 7: The results of the questionnaire

As can be seen the overall response level is quite high. Only statement number 15 has an average grade of below 4. One of the objectives of SPMonitor is to provide time savings in aircraft manufacturing processes, especially by enhancing anomaly management procedures. Apparently, some of the test participants were not convinced that they could save a substantial amount of time in dealing with unexpected events by using SPMonitor. On the other hand, it may have been difficult for test participants to provide any accurate estimates of how much time the system would save them, as some of them were not the intended end users of the approach they evaluated. The written responses also reflected the positive reception of SPMonitor, as they included many encouraging comments. For example, one participant stated that “It's an interesting tool to present to EADS business units”. These kind of comments increase the motivation to further develop the tool.

The feedback obtained from the focus group session gave us many fresh ideas for future research work and the development of SPMonitor. For example, many of the focus group members suggested that SPMonitor could be useful in the domain of project management. A concrete use case example is monitoring the progress of a software development project in order to see the current state of different tasks and examining potential problems that may come up. Potential was also seen in using the tool in project planning, where SPMonitor could enhance such tasks as project configuration and resource assignment. Finally, the focus group suggested numerous other domains in which SPMonitor could be useful. These domains include education, real estate maintenance and health care.

Many of the focus group session participants also considered that SPMonitor could use the capabilities provided by semantic technologies more effectively. Currently, SPMonitor stores data related to past workflows, which enables the performance of sophisticated analysis and diagnostics reports. Thus it supports the design phase of workflows, by enabling to better estimate how long the execution of workflows with certain types of activities, transitions and resources (e.g. tools and operators) will take and what kind of anomalies can be expected. However, if the tool were to use the powerful reasoning capabilities provided by semantic technologies more efficiently, it could dynamically produce more sophisticated analysis containing information describing issues such as data dependencies of a workflow in run-time. Additionally, the more efficient utilisation of semantic technologies could improve the SPMonitor's ability to deal with unexpected events.

Although, the evaluation carried out in this study gave some insight into the potential of the tool, it must be borne in mind that the actual verification of the approach can only be done in a real production environment where the way in which the approach copes with the demanding requirements of final aeronautical assembly lines can be tested. The feedback provided by end users is also likely to provide a more accurate picture of the usefulness of the tool, as they have more experiences from using the approach. Moreover, the testing in a real production environment will facilitate the gathering of quantitative data, which will provide more accurate information on how much time SPMonitor actually saves, or whether it has an impact on the occurrence rate of anomalies, for example.

6. CONCLUSIONS AND FUTURE WORK

Digital means and computer-supported collaboration techniques are being used widely in engineering in many production domains. It is adopted in particular in the modelling and simulation of the manufacturing processes in large industrial companies. However, the monitoring and visual support to facilitate the coordination functions of run-time productive environments is still a challenge.

In this paper, we have proposed semantically empowered visualisation aids to support collaborative processes and corrective decision-making for various actors, such as operators, support teams and station managers involved in the execution of the productive process. The resulting approach dynamically visualises information related to workflows, including the processes, participants and other resources involved. An important aspect is also to show illustratively the possible anomalies that may occur during a workflow and allow users to react more efficiently to the problems. The ability to provide a “global view” of workflows improves the overall comprehension of processes and allows users to gain a better overall picture of the whole ecosystem.

The approach also specifies a new workflow ontology that defines concepts, relationships and attributes needed for describing workflows and other related information. The semantic modelling and processing of workflows has many benefits as it enables more sophisticated diagnosis and analysis possibilities, and also facilitates more efficient run-time decision-making capabilities. Moreover, the use of semantic technologies enhances the integration of heterogeneous workflow-related information into a single data model. However, the utilisation of semantic technologies also presents a challenge and therefore further research must be carried out on how to better exploit the full potential they offer. Additionally, more information regarding what kind of diagnostics and analysis information would be most useful for end users should be acquired from domain experts.

The approach has been validated within the actual application and use cases associated with final aeronautical assembly lines. The evaluation was carried out in two phases: firstly a focus group session was organised and secondly, analytical user tests were performed. The focus group session provided numerous suggestions on possible directions in which the tool could be developed. The analytical user tests provided information on the system’s ability to meet its requirements in terms of usability and perceived usefulness. Through the light evaluation performed in this stage, SPMonitor has demonstrated its potential in terms of the improvement of productivity, flexibility and product quality. However, a thorough verification of the tool would require more extensive testing in a final production environment.

Apart from the aeronautical domain, we believe the tool can also bring about benefits to other application domains such as logistics, education, real estate maintenance and health care, thanks to the extensible capabilities of the tool in terms of domain-specific ontologies and additional visual graphics libraries.

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PIV

DESIGNING SITUATION AWARENESS: ADDRESSING THE NEEDS OF MEDICAL EMERGENCY RESPONSE

by

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Designing Situation Awareness

Addressing the Needs of Medical Emergency Response

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Abstract: The effective support of Situation Awareness (SA) is the core of many applications. In this paper, we report a progress on the research towards the complementing of the existing studies with new knowledge, on engineering of SA in particular keeping in mind a complex multi-stakeholder context of existing and future knowledge intensive intelligent environments. A medical emergency response use case is used as an instantiation example to evaluate our engineering thoughts.

1 INTRODUCTION

The importance of Situation Awareness (SA) has been firstly recognized for crews in the military and aviation domains. The most prominent and complete work in this direction is a Theory of Situation Awareness studied and consolidated by Mica R. Endsley (Endsley, 1995). In her work the theoretical model of situation awareness and in particular its role in human decision making is defined. From the application point of view this research addresses mostly the needs of various time-critical environments, such as air traffic control, large complex manufacturing systems, some medical systems and tactical and strategic systems. These systems are in a sense closed systems of single provider supporting strict top-down design and development approach and aim at addressing the needs of a “single operator”.

On the other hand the increased availability and robustness of sensors, the wide-spread use of the internet, as well as intensified research in the area of the content convergence and social media have led to the definition and acceleration of various research fields and phenomena that draw on the advances of these technologies, Pervasive computing, Ambient Intelligence and Internet of Things (IoT), as well as cloud computing, which define a vision where in the future distributed services and computing devices, mobile or embedded in almost any type of physical environment all cooperate seamlessly with one another using information and intelligence to improve user experience. The support for Situation Awareness is equally important in this new context. The value of SA can be found in the product manufacturing domain, emergency management, design, supply chain management, and equipment remote maintenance, to mention a few applications. The Situation Awareness requires applications to support management of data, knowledge and related services in an integrated and sustainable way. Mastering of “simplicity” and “openness” will be deterministic for the digital products, application and services successful in the future. Openness in the creation of products and services allowing various independent networks of stakeholders to participate in the services creation process will enable the complementary bottom-up approach in smart systems development. Simplicity is demanded by users. Simplicity is related to usability and there is a trend in industry to conflate these terms as much as possible. Better usability will increase user acceptance of technology, which is crucial for products take-off in many contexts. The purpose of the system may play an important role in defying of respective elements that influence system acceptance from the end-user as well as the developer and business point of view.

In this research we aim at extending the existing studies in the field looking on SA according this new context. A medical emergency response context is used as an example to instantiate and to evaluate the respective design thoughts. Various stakeholders

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dealing with Situation Awareness, such as end users of the system (i.e. emergency responders), application developers and business actors are examined. By applying the user-centred approach to elicit the requirements for patient safety during emergency medical response, one of our contributions to the state of the art is to extract the "simplicity" hidden in apparently complex emergency context. Our second contribution lies in the resulted domain model and respective knowledge oriented architecture, which are defined to guide the development of desired situation awareness.

In the following section, the related studies on SA as well as the motivation for this research are further discussed. The aim is to capture challenges and needs still to be addressed in developing of SA and therein to facilitate innovation and more substantial system design. In Section 3, we discuss a model based SA design for medical emergency response context. Conclusions are summarised in Section 4.

2 SITUATION AWARENESS

SA originated with aviation practitioners. After the research has spread to other environments, such as air traffic controllers, nuclear power plant operators, anaesthesiologists and automobile drivers in particular addressing cognitive tasks that operators in such environments may face, thus extending the theoretical model defined by Endley (Endsley, 1995 & Endsley, 2003).

Looking on the relevant advances in research in the area of pervasive ubiquitous computing environment and IoT, a related concept to SA is the notion of Context Awareness (CA), which is defined as "any information that can be used to characterise the situation of the entity" (Dey, 2001). The term Context Awareness and Situation Awareness are used interchangeably by some authors as they mean the same, however there is an important difference in their usage. The CA aims to enable better service delivery through proactively adapting use and access of information, physical resources and multi-modality feature of human-computer interaction process with respect to available context information (Soylu, 2009; Schmidt, 2012). In contrast, SA is the perception of the elements and "events" in the environment related to the entity (i.e. user) or in other words, it is simply about knowing and understanding what is going on around. This understanding may lead to some action taken by the user.

While the methodology towards the developing of context-aware applications for various intelligent environments has appeared (Dey, 2001; Hong, 2009; Perera, 2013), there has been a little focus put to support the situation awareness in this new context (Chen, 2012). The existing approaches aim mainly at the addressing of development of domain specific applications and improvements of existing technology according to the theoretical models introduced earlier (Endsley, 2003). For example, the SA needs of an operator in road traffic management domain are enhanced by developing a number of ontology based applications (Baumgartner, 2010). The machine learning algorithms towards the recognition of situation are presented in (Häussermann, 2010). A role of semantic technologies in improving SA is discussed in (Smart, 2007). In the domain of emergency management, the research has been mainly focusing on tackling of organizational aspects to achieve a sufficient shared SA (e.g. Sapateiro, 2007; Seppänen, 2013).

The existing approaches lacked the touch of widely adopted software engineering practices where the requirements to SA engineering are mastered by examining various design-view points, actors involved, and the domain specific aspects such as standards and accepted work practices, as visualised in Fig.1. Developing the effective and sustainable Situation Awareness necessitates the availability of respective Model, which is created to build the description of the problem domain in software engineering and to define the system development process. Models are very much associated with the domain they present. Accordingly, in the following section we illustrate our approach to the design of Situation Awareness by researching and developing the domain specific model to tackle the needs SA in a medical emergency response context.

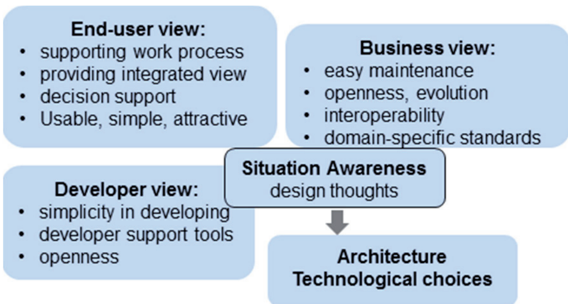

Figure 1: Design views in SA engineering.

3 EMERGENCY MEDICAL RESPONSE

The information systems for emergency management are based on information provided by various actors, by diverse collections of sensors in the field and information supplied by human volunteers. The information may come in different forms such as field reports, images and remote sensing information. In order to achieve SA, various knowledge and information models need to be aligned. It is widely acknowledged that good SA leads also to good decision making (Feng, et al. 2009). Moreover, as various actors (and accordingly various heterogeneous information infrastructures) are involved as information providers in the emergency management context, there is a demand for the means to support the interoperability among different information sources towards their access and information reuse and further acceptance of the system by business and earlier adopters.

3.1 End-user View

The methods for the collection and analysis of general emergency response user needs towards the creation of domain model involved literature and clinical practice reviews and face-to-face interviews with stakeholders (e.g. the London Ambulance Service, the Vienna Red Cross, the Sofia Military Medical Academy). This led to the codification of the principle five spaces, related actors and their actions directly linked to medical emergency response: (1) Initial Alert: the phase, where the initial alert is being managed, usually a 112 call center or Public Safety Answering Point (PSAP); (2) Emergency Medical Service (EMS) on the Way: the phase, in which an EMS team is dispatched to emergency event's location; (3) Field Management: the event's site where the people requiring urgent medical help are located; (4) Transport: the phase, in which an EMS team takes patients to a First Receiver; (5) First Receiver: the phase, in which the First Receiver, usually hospital, prepares for and later takes over the care of the patient. The emergency responders working in each of these five phases/spaces have sets of patient-related tasks, which are the same, irrespective of country or type of incident. These are the tasks that form the basis for the generic set of requirements for technology and situation awareness and decision supports, discussed next. The more the actions across the spaces are interlinked by effective information sharing technology and the more provisions for mutual visibility, early situational awareness, and decision support are provided, the more the phases are enabled to run in parallel, therefore saving time and becoming more effective in saving lives.

3.1.1 Situation Awareness Model

A Common Information Space (CIS) introduced to maximise the quality of available information and its outcome across five operational conceptual spaces of emergency medical response, Decision support points and Information sharing patterns constitute the Situation Awareness model. The Situation Awareness model is represented in form of the sequence diagrams in Fig. 2. The purpose of these sequence diagrams is: 1) to clarify the decisions that different actors make during the course of an incident and explain how the system supports decision making; 2) to illustrate the collaborative nature of decision making and represent what kind of critical information is required to support different actors with their tasks; 3) to represent the important information flows that potentially exist between involved actors mediated by a knowledge management system in form of notifications and alerts.

The emergency management process is started as PSAP receives a call to the emergency telephone number. Usually, the caller provides basic information about the incident including the type and the location of the incident and injured if any. PSAP staff reports the received information to the CIS system and determines also a priority dispatch code for the event. The inserted information is transmitted to the Decision support system that should be able to analyse the data and to generate recommendations for resources that should be invited to manage the incident. The recommenda-tions are returned to the CIS system, which in turn should notify PSAP staff about the recommenda-tions. Subsequently, PSAP staff may analyse the recommendations to make the final decision about the resources that are invited and dispatched. Next, PSAP staff communicates the dispatch information to selected EMS staff members and, additionally, informs hospitals through the CIS system. After that, both EMS staff and the field commander should compare the incident details (e.g. the number of patients) against dispatched resources and evaluate whether the required resource estimations are accurate and justified. If necessary, both of the aforementioned actors can decide to dispatch additional resources for the incident. The field commander also performs task allocation for EMS staff members. The Decision Support system may support this activity by creating

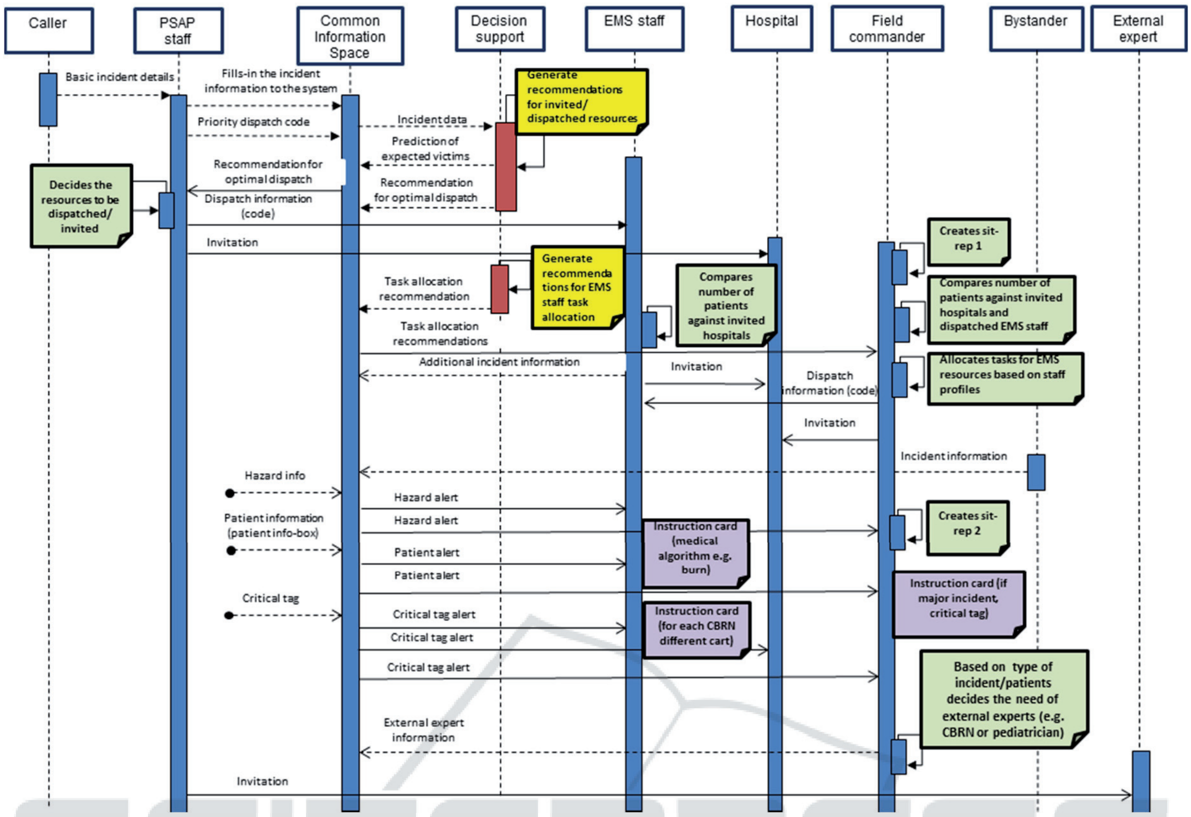

Figure 2: Sequence diagram of a collaborative decision making in an incident situation.

recommendations for task allocation utilizing, for example, personal profiles that describe the capabilities of involved EMS staff members. Actors can also set critical tags to the system to indicate that the incident involves potentially dangerous chemical, biological, radiological or nuclear materials. The final decision making point presented in the Fig. 2 considers whether external experts should be invited to the scene of an incident. Based on the incident type, injuries of patients and/or the existence of possible hazards and critical tags the field commander may decide to insert information about required external experts to the CIS.

The activities, decisions and communication flows that are usually executed in the following phases of an incident management process are not illustrated in the sequence diagram due to the space limit, however they are explained in the following. Once EMS staff has examined the patients, patient data (e.g. the results of triage) is reported to the CIS. Next, the received information is analysed by the Decision support system towards the generation of recommendations for allocating patients to hospitals. The recommendations are constructed by comparing patients' reported injuries against available hospital data including provided specialities, location and the number of available beds. Based on the received recommendations EMS staff can decide the patient allocation and is able to send allocation alerts to hospitals and medical transportation. The allocation alerts include the IDs of the patient and the hospital receiving the patient. In the next phase, the CIS system may communicate the location of hospitals and current traffic information to the Decision support system that should be able to process the information and to generate route recommendations for transportation vehicles. Once a patient arrives to the hospital the hospital personnel downloads a patient form from the CIS system thus acknowledging the arrival.

Typically, the transportation personnel and responders in the field also utilize specific cards that offer guidance and thus facilitate the treatment of different kinds of patients or allocation of required resources.

The defined Situation Awareness model is used as a basis to formulate the required knowledge models for the Common Information Space and to propose the overall architectural pattern that can be used to achieve the desired SA functionality. The proposed architecture and knowledge models, which take into account the developer- and the business-views are discussed next.

3.2 Developer and Business Views

Glossaries and vocabularies play a significant role in emergency management due to the importance of clear communication during disaster response. It is a good practice to use standards if available to enable information sharing interoperability. Several standards addressing data modelling and data exchange formats related to medical emergency response have been designed so far. Based on the conducted research (Kantorovitch et al. 2015), OASIS EDXL based models (EDXL, 2015) appear more promising to address the needs of medical services in the context of emergency. To date, it is the most complete and mature effort to facilitate emergency information sharing and data exchange across various actors - public, commercial and also medical involved in the process of emergency management. Consequently the EDXL-based vocabularies have been selected as the central knowledge models to utilize. Obviously there is no possibility of universal agreement on any conceptual scheme including EDXL, however it is argued that a practical common ontology does not need to have universal agreement, it only needs a large enough user community to make it profitable for developers to use it as a means to general interoperability, and for third-party developer to develop utilities to make it easier to use.

In addition, in order to support evolvability, the system solutions have to take into account requirements that arise from anticipated changes on environment, technology and stakeholders' needs. Fortunately there is already accumulated knowledge of well-known general software design principles presented as architectural tactics and patterns that can be used to guide design. Architectural tactic is a characterization of architecture level decisions that can be used to achieve a desired quality attribute response. Evolvability is typically associated with modifiability, which can be addressed by a tactic localizing changes by increasing cohesion, preventing ripple effects of changes by reducing couplings, and deferring binding time to support dynamic adaptability (Bachmann et al. 2007). Studies have identified several architectural patterns supporting evolvability, most important examples being layering, Model-View-Controller (MVC) pattern, and use of plug-ins (Bode and Riebisch 2010). Based on the best practices identified, the architecture of the system is designed to adopt layering and Model-View-Presentation (MVP) architectural pattern that itself is a derivation of MVC. Layers defined in MVP pattern are presented with shades of blue in Fig. 3.

Model layer captures the information on problem domain i.e. individuals of incidents and their participants. The model stores dynamic data into RDF store, which directly manages its logic and consistency with axioms and rules. The Incident ontology is the core ontology of Model. Model is constructed using both domain specific and generic ontologies shown as grey layers. The Incident ontologies and EDXL concepts are structured in an extensible way and constructed according to Linked Data (LD) principles. Both, the developed Incident ontologies and EDXL vocabularies are released as an open source to GitHub software repository for their further reuse (COncORDE, 2016).

Presenter layer typically retrieves data from the model, and formats it to be useful in the views (facilitated e.g. by REST API/JSON format). In the emergency context the presenter layer contains queries that report the overall situation and also may enable alerts and notifications presented in Fig.2. Presenter layer also supports queries and reasoning based on generic ontologies for time, location and organization or personal information. When other external vocabularies are utilized by Model, new presenters for them can be added. In addition, Presenter Layers is designed to support other functions and services of the system, such as ontology-assisted information extraction, decision support algorithms and overall management of heterogeneous incident related content.

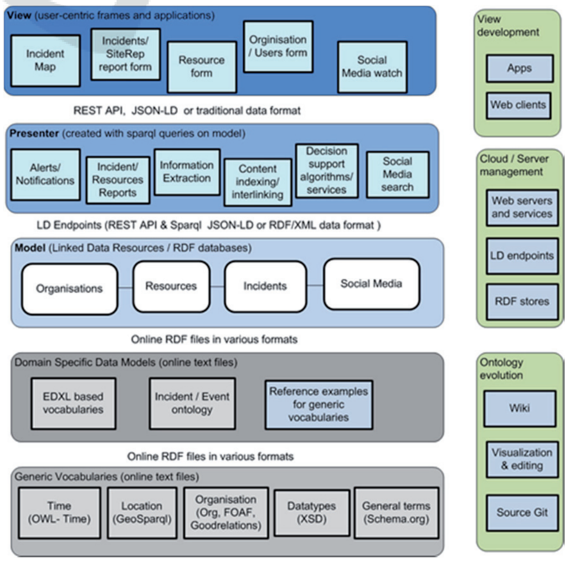

Figure 3: The knowledge oriented architecture.

Finally, a *View* can be any output representation of information, such as a diagram or it may contain multiple views, such as a map with several information visualization layers.

Layers on the right shaded as green represent stakeholder specific development, maintenance and evolution related aspects of the system with examples of supporting tools. For instance, ontology evolution is supported with version control using GitHub with wiki as a means for documenting the rationales for changes in ontology. In order to ease version control, ontology source is developed using textual Turtle format.

The proposed framework utilizes two of the main strengths of linked data technologies. First is that the evolution of ontologies used by models can be opened to collaborative work among developers. Second is that the models themselves can be extended and tailored for the specific needs of systems and user views by choice of external vocabularies and ontologies.

4 CONCLUSIONS

This paper has provided the detailed technical description of a model based approach aiming at achieving Situation Awareness and support for decision making in a dynamic medical emergency response context. The effective exploitation of domain models, architectural tactics, linked open data technology and domain specific vocabularies aim at the interoperability, better acceptance and evolution of the developed system. The use of Web standards and a common data model makes it possible to implement applications that operate over the complete integrated data space. The focus of our future work is put on further prototyping of the proposed SA framework. The developed decision support services are based on the mathematical modelling of optimization problems for timely allocation of resources and on semantically supported domain knowledge modelling, as well as on the machine-learning-based prediction of emergency incident expected victims and subsequently demand for resources.

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SUPPORTING THE INITIAL STAGES OF THE PRODUCT DESIGN PROCESS: TOWARDS KNOWLEDGE AWARENESS AND INSPIRATION

by

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Supporting The Initial Stages of The Product Design Process: Towards Knowledge Awareness And Inspiration

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Abstract

The creation of new products and services is an everyday activity for many industries, often assisted by professional design studios. It is evident that extensive knowledge is required by designers during the conceptual product design process, matching the complexity of design problems. Techniques based on association, analogy and metaphors are often used to facilitate the process of creative thinking and inspiration leading to new product designs. This paper presents a novel semantic tool, which has been developed to seamlessly assist product designers with knowledge management tasks during information discovery and support the formulation of new product concepts. The technology can be used in combination with a sketching application to support the generation of relevant visual content, helping to stimulate associative thinking, and thus assist creativity at the initial stage of the product design process.

Keywords: Conceptual Product Design, User Experience, Awareness, Semantic Technologies.

1. INTRODUCTION

The exponential increase in the volume of visual material available via the web is now accepted as the norm. Much of this upsurge results from the opening up of visual repositories and the rapid growth of social media. This is potentially an extremely valuable resource for the design profession to draw upon for inspiration and knowledge. However, the sheer quantity presents new difficulties in finding particular images. Designers have gone from *looking for a needle in a packet of needles* to *searching for a needle in a haystack*. The design profession relies on the use of visual resources to communicate, collaborate and inspire new ideas. The research reported in this paper describes the development of tools to help designers make better use of design resources. The initial stage of the product design process typically begins with the initiation of a design brief. A design brief may be a vague statement provided by the client, or it may be a more detailed design specification. It commonly provides basic information about the challenges the new concept should address. The early, conceptual stage of the process is dominated by the generation of ideas, and the term 'ideation phase' is used to denote this process. The ideas are subsequently evaluated against criteria set out in the design brief, and agreed with the client. The design process can proceed in many different ways, as illustrated in Figure 1 [1]. When developing new concepts, existing solutions and ideas that are already in the market are considered. It is therefore critical for any product development team to be aware of past solutions, market data, and emerging technologies, in order to avoid duplication of effort and to stimulate creative thinking.

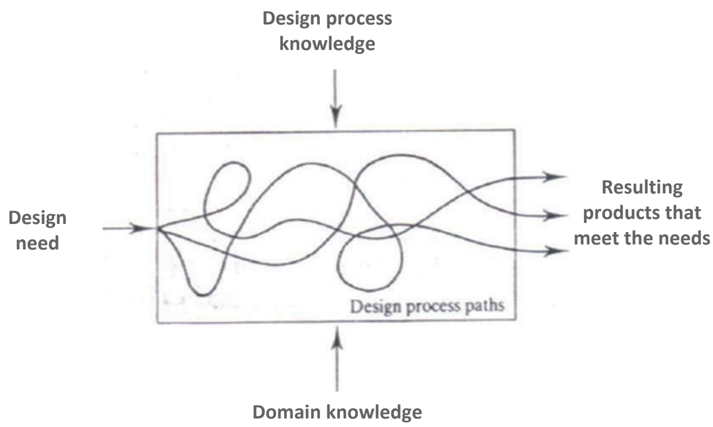


FIGURE 1: Knowledge used in the design process [1].

Creativity is a quality that is highly valued, but not always well understood in the field of design [2]. Bringing together previously existing concepts in new and unexpected ways can be original and considered creative. Thus, creativity is the ability to see connections and relationships where others have not. That creative thinking is based on knowledge of previous work in a given field is the rationale for exploring the aspects and foundations of the area as a resource for future research and creative work [3].

Images are a powerful resource to inspire and convey meanings, in particular emotional values, characteristics and experiences. Selected visuals can serve as an important tool to communicate values not easily expressed in words and can convey ideas in an accessible way. Images offer a vehicle by which designers and clients can shared a language, therefore assisting the development process. Images collated in a 'moodboard' convey specific visual qualities and emotions [4, 5]. The undertaking of such research is an essential yet time consuming component of the design process.

Due to the interdisciplinary nature of the design process, a semantic gap exists in the use of terms and concepts. Designers and clients have to generate and exchange ideas. A variety of tools can be used during this process, which results in the generation of an enormous amount of interrelated heterogeneous data, all of which adds to the challenge of storing and retrieving design content.

During this research phase, it is typical for designers to search for and save a vast quantity of visual data. There are few applications focusing on the conceptual phase [6] catering specifically to the needs of the creative industries, however research suggests that a range of online platforms such as Google Images and Pinterest, are used during this visual research work [7]. Nevertheless, each available system has shortcomings, and no currently available platform answers to the intricacies of this type of work. Images returned by Google is considered predictable and repetitive. Visual repositories like Pinterest return a greater breadth and specialism of visual data, however finding the 'right' content here is problematic since tags are input subjectively by the uploader.

When selected, designers save visual and any other content to their repository of choice, either local or remote. Tagging each image or document individually, then saving it to the repository is the logical approach to an information scientist, however when designers are dealing with tens, hundreds, even thousands of jpegs, and when working to strict client-imposed deadlines, this is unrealistic. The detailed process of tagging individual files is a hindrance to the free-flowing nature of the design process. There are other problems associated with this approach [7]. First, it is often difficult to find and re-find saved particular design content amongst many files. Second, viewing images together is important for the purpose of creating moodboards, yet for most existing applications render the viewing and a selection of images at once problematic. Third, files may be reused and referred to on many occasions subsequent to the completion of the original piece of work for other projects.

It is suggested that the initial conceptual stage of the design process is the most knowledge-exploration intensive phase, however current design tools offer limited connection to knowledge management software. Product designers may not necessarily have a ‘technical’ background or in-depth experience of knowledge management systems, and as a result, the usability aspects of knowledge management functions are an important consideration in the design of specialised supporting software tools. The acceptance of a proposed solution is crucial. Ease of use, usefulness and ease of adoption have been found to be important elements of user satisfaction and acceptance [8, 9, 10]. Designers as a group are often early-adopters of new technologies, however usability aspects of software are of utmost importance. This paper presents a new semantic knowledge management toolset that facilitates the early stages of various products design, and which addresses the needs of professional designers. The toolset is web-based and can be easily customised to work with other web-based product design or knowledge management systems.

In section two, the various tools that are required to support designers with knowledge management tasks are discussed. The methods of human computer interaction (HCI) and design thinking were applied to learn how knowledge activities are incorporated into the design process. Section three presents a new conceptual prototype, which was interactively developed with assistance and in collaboration with domain experts. The identified needs and feedback from designers and usability researchers was used as a basis for the development and refinement of the architecture, and the deployment technology, for the proposed solutions. The details of the technical implementation are discussed in section four. The prototype tools were evaluated by professional designers and usability experts. The evaluation results are reported in section five. Conclusions about lessons learned and future research are presented in section six.

2. HUMAN TECHNOLOGY INTERACTION - NEEDS

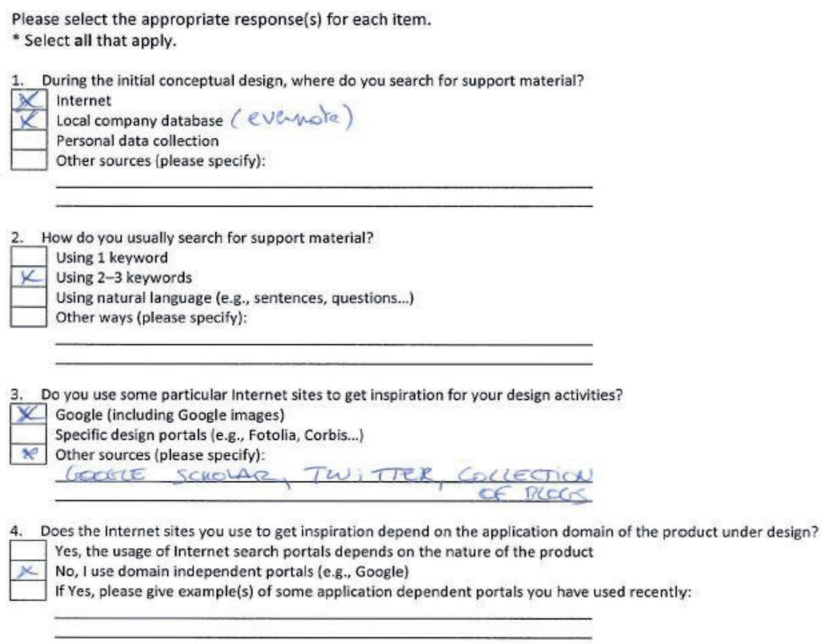
The requirements for the supportive knowledge management technology detailed in this paper have been acquired through a multi-faceted iterative approach, including a literature review focusing on what is needed to support knowledge exploitation processes and creativity across a design team [11, 12], as well as interview based research with professional product designers at internationally recognised consultancies (DesignLab, Athens, and Studio Levien, London).

A crucial element of this process is the analysis of design teams in action. Generally, the initiation of a new project can start in different ways. The design studios may get design briefs from the client, but it is also often the case that they generate their own project. In the former, the brief may detail: a description of the product to be designed; a profile of the target end user; a description of the context of use; the currently available technologies and competitive products already on the market; market positioning for the new product; target cost; functional and aesthetic features; design requirements, etc. The process of conceptual design iterates back and forth before the concept for the new product is crystalized. If, for example, the requirements for a project are not extensively specified, the design team may start their own online research for new concepts, specific information and inspiration. Alternatively, in the case where a brief is specific and detailed, and discussed with the client, designers analyse the information, enriching it by performing additional online searches and making use of any existing company databases and other sources of data. Relevant data, such as images, drawings, notes, specifications, reviews, and websites are collected and saved to a design project space on the studio hard drive. As noted previously, the collected information is usually numerous, heavy in storage, and can be difficult to retrieve from the hard drive.

Designers may also create digital or physical sketches, which can be photographed and uploaded to the project space. In the next step, a moodboard can be created by adding images, videos and other material, to which annotations in the form of notes and keywords are added before storing it to the project space. The moodboard contributes to the creation of a shared vocabulary for the project. In addition, a set of personas for the product can be created. For this task, a short description of the end-user's profile is created and used to search on Google for images to illustrate these personas. Designers also research similar products online. The competitive products are categorized and rated according to their functionality and usability.

As described, the research undertaken by design companies illustrates that storing and logging vast amounts of creative stimulus material is a demanding task in terms of the resources needed for finding, sharing and accessing the right material. Furthermore, it is paramount to ensure that access to the 'material' is centralised, and remains as simple and clear as possible. The new software is intended as a tool to enhance the creative process and should therefore not distract from the user's flow of creative ideas. After the interview-based research with professional designers, several '*timeline'* mock-ups were developed with the aim of interlocking parts of the support functionality.

As well as analysing use case descriptions and scenarios, designers were asked to complete a questionnaire with the purpose of gaining understanding of how professional designers approach the management of design content. Questions and answers guided the design and prototyping of possible solutions. Designers were asked to provide insights into: how they typically search for the content used as a basis for conceptualizing the new product (e.g. using keywords, natural language, searching for images), what sources of information they use to generate new ideas, and the nature of the content to get the inspiration for their design activities. Figure 2 shows an example of one such completed questionnaire.


Please select the appropriate response(s) for each item.
* Select **all** that apply.

1. During the initial conceptual design, where do you search for support material?
   - [X] Internet
   - [X] Local company database (evernote)
   - [ ] Personal data collection
   - [ ] Other sources (please specify):

2. How do you usually search for support material?
   - [ ] Using 1 keyword
   - [X] Using 2–3 keywords
   - [ ] Using natural language (e.g., sentences, questions...)
   - [ ] Other ways (please specify):

3. Do you use some particular Internet sites to get inspiration for your design activities?
   - [X] Google (including Google images)
   - [ ] Specific design portals (e.g., Fotolia, Corbis...)
   - [X] Other sources (please specify): GOOGLE SCHOLAR, TWITTER, COLLECTION OF BLOGS

4. Does the Internet sites you use to get inspiration depend on the application domain of the product under design?
   - [ ] Yes, the usage of Internet search portals depends on the nature of the product
   - [X] No, I use domain independent portals (e.g., Google)
   - [ ] If Yes, please give example(s) of some application dependent portals you have used recently:

FIGURE 2: A questionnaire completed by a participant.

A detailed analysis of the questionnaire revealed that designers rely on resources available from the consultancy and the client's own database, such as documents or sketches produced in the course of previous projects, as well as a range of external information sources such as electronic books, images, music, online design magazines and image collections (e.g. Getty, Flickr, Co.Design, Yatzer, Designboom, Design Observer and Pinterest). In addition, general purpose search engines such as Google were mentioned as a daily source of information, regardless of the type of project. Ideally the knowledge management tools should be able to cope with various content locations and contexts in a seamless and unobtrusive way. From a content management point of view, the understanding of vocabularies used by team members from other disciplines is the technical limitation which is most experienced by the design team members [13].

The requirements resulting from the analysis of the questionnaire results and interviews are summarised in Table 1.

Category	Designer needs	Derived technical requirements
Content search	Effective search of company's local databases e.g. documents and sketches produced in the course of previous designs	Availability of semantically rich content metadata Capacity to effortlessly add annotations in various types of content
	Provides convenient ways for content searching simultaneously from multiple data sources. Ability to examine results of different searches in a single view	Capacity to interlink existing and new uploading material
	Provision of the suggestion of relevant material	Identifying relevant contents automatically, establishing connections
Content presentation	Dynamic content organization, filtering	Support for dynamic indexing of content, learning ontologies, crowdsourcing
Common vocabularies	Common content metadata model	Availability of design world vocabularies/knowledge model
Knowledge model management	"No management" i.e. seamless support for managing design taxonomies and vocabularies	Facilitates the understanding of design vocabularies and taxonomies. Enables the creation of new taxonomies and edit existing ones
Creativity support	Knowledge awareness as part of working processes i.e. linking of content recommendation to existing work processes and tools such as e.g. sketching, design briefing	Knowledge Extraction technology
Usability, UX	Simplicity and clarity enabled by UI, as intuitive as possible Support for automatic content metadata provision	Automatic knowledge extraction, seamless semi-automatic content annotation interface, intuitiveness

TABLE 1: Requirements to knowledge management toolset.

The content management toolset was designed to take into account the findings and requirements as described. The next section explains the philosophy and conceptual prototypes of the solution in more detail.

3. KNOWLEDGE AWARENESS – CONCEPT PROTOTYPE

In principal, the designer is always informed about related and relevant material to that may already be stored in the designer's local repository. For example, taking the design brief, uploaded to the system as input, the design-brief analysis application is able to search and suggest content related to previously created content in other design projects, or available on the Internet. To illustrate this, Figure 3 shows the ability of the tool to find, represent and link various contents related to a project for a 'smart running jacket' from local project databases, as well as utilizing Google Search, Flickr and online collections maintained by the Victoria and Albert museum. In the next step, the designer may carefully review the suggested images and store them (along with the generated semantic metadata) in the system for future use.

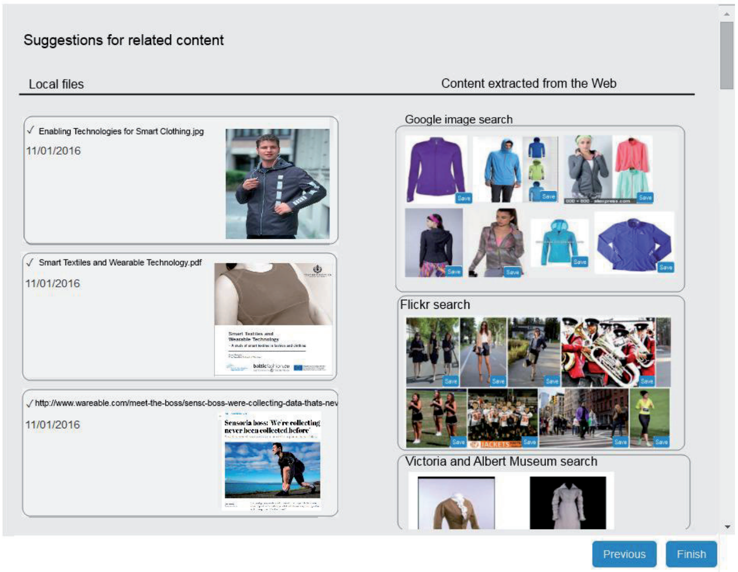


FIGURE 3: Relevant content suggested based on the information extracted from brief.

Sketching is an essential tool for many designers. Sketching is a means by which to explore concepts and to communicate ideas. Sketches can be low fidelity, such as pencil drawings, or more technically advanced, such as isometric computer aided designs. Sketching may overlap with the rapid creation of low fidelity prototyping, such as 3D models. Promising ideas can be scanned or photographed, and uploaded to the project repository.

There is experimental evidence to suggest that the interpretation of previous sketches can be used as a source for modifications in the design space, thus leading the project in new directions [14]. Many studies of creativity in design connect 'unexpected discoveries' with sketching [15]. To support and experiment with this research, interactive sketching application has been developed that supports the generation of new ideas and concepts. Designers may start by sketching concepts using familiar digital sketching tools, or with pencil and paper. As soon as the sketch is uploaded into the active window (see Figure 4 – on the left side), the system starts to work by searching for relevant data in the form of other sketches and images based on the semantic similarity to the original sketch. The search results and associated images update according to the actions taken by the designer. The designer may for example make modifications to the original sketch, edit automatically generated semantic metadata, and upload other sketches from previous projects.

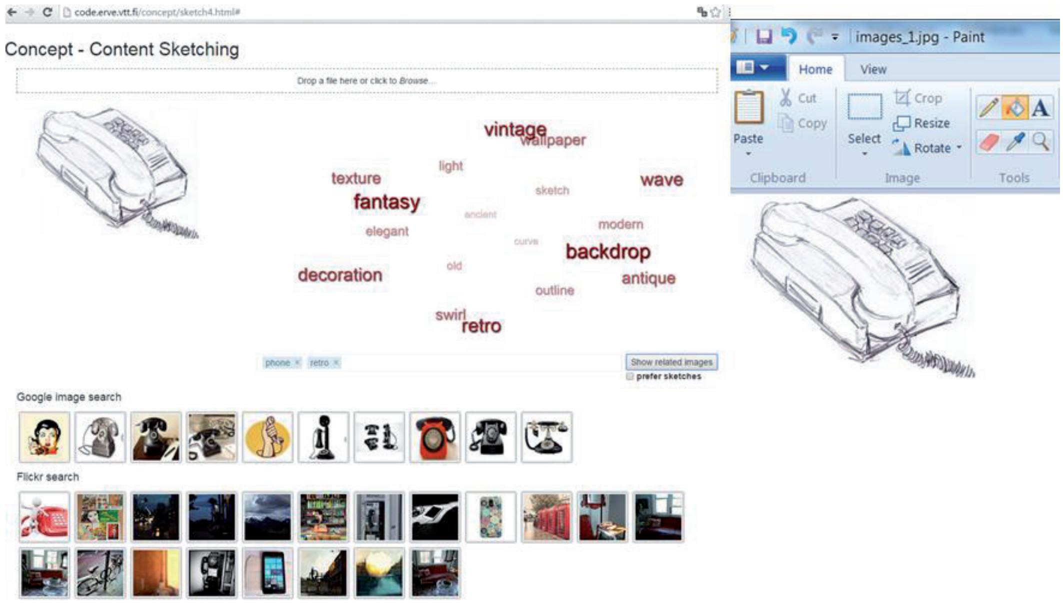


FIGURE 4: Interactive sketching application.

The next section explains the architecture and implementation of the semantic tool in more detail.

4. TECHNICAL IMPLEMENTATION

Semantic annotation, search and recommendation services, as well as the set of knowledge modelling tools and knowledge extraction technology, constitute the intelligence of the proposed knowledge management environment (see Figure 5).

The availability of rich content metadata is necessary to achieve effective personalised and dynamic content management. Semantic technologies and tools have undergone significant development in recent years. Methods for knowledge exploration based on semantic annotation using ontologies are recognised as a powerful approach, which can make the processing of information resources more 'intelligent' – i.e. machine interoperable, effective and meaningful [16, 17, 18]. Ontologies can provide elegant mechanisms to organise content in logically contained groups while linking them with other related concepts. The recently introduced Open Linked Data technology [19, 20, 21] has the potential to facilitate the interlinking of unconnected documents images from various data sources to generate large interlinked data ecosystems. The main components of the proposed support environment are explained in more detail in the following sections.

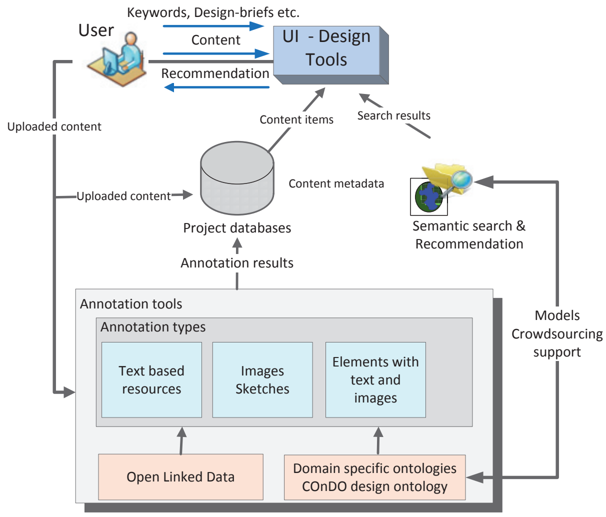


FIGURE 5: Content management architecture.

4.1 Content Annotation

The annotation of text and visual resources is performed semi-automatically. This means that the system automatically generates suggested metadata, but the user has the ability to edit it (i.e. to control the technology). The process flow of content annotation in the example of provision metadata for the textual resources is illustrated in the sequence diagram presented in Figure 6.

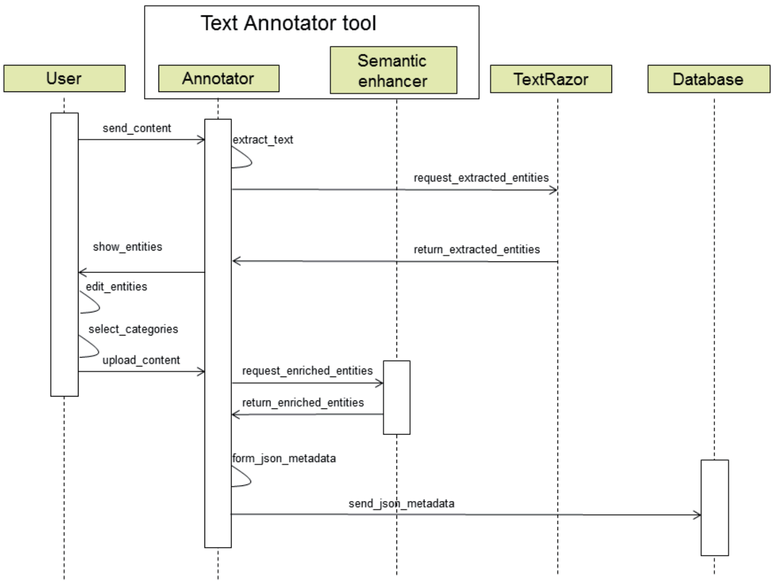


FIGURE 6: Sequence diagram of text annotation process.

The annotation process begins by indicating the content to be annotated. The content is sent to a Text Annotator sub-component that utilizes Boilerpipe [22] API for extracting textual content from web pages, Apache PDFBox [23] for parsing text contents from PDF documents, and Apache POI [24] for parsing text contents from Microsoft Office documents.

In the subsequent phase, the Text Annotator component sends the extracted text to the TextRazor tool [25], which supports identifying named entities from texts. After analysing the text, TextRazor returns the extracted entities (i.e. keywords or tags) to the Text Annotator component, which is shown to the designer using the system. The designer is able to edit the list. In addition, the domain-specific concepts are presented and can be selected by the user (the domain specific design ontology is discussed in section 4.2). The annotation of visual material is, in many ways, similar to the annotation of text-based resources. The image recognition and tagging open software [26] is leveraged to facilitate the extraction of high-level semantic features from images and sketches.

Once the designer has approved the content annotation data, the content can be uploaded to the system. Subsequently, the Text Annotator component sends the tags to the Semantic Enhancer sub-component that enriches the extracted entities by utilizing Open Linked Data knowledge bases. The enrichment process aims to facilitate machine-readable comprehension, and to improve the findability of the content items. The Semantic enhancer component uses the APIs provided by DBpedia [27] and ONKI [28] services. DBpedia extracts structured information from Wikipedia and makes this information available on the Web. Furthermore, the ONKI service contains Finnish and international ontologies, vocabularies and thesauri.

The Text Annotator tool utilizes the APIs of the above-mentioned services in order to search terms that are somehow associated to the entities extracted by TextRazor and Imagga. A weighting (number from 0 to 1) is assigned to the enriched metadata concept based on the semantic relationship (i.e. measured semantic similarity [29]) between the original extracted entity and the concepts in DBpedia and ONKI ontologies. Besides the highest weighting (number 1) is assigned to keywords provide by user, if available. In the final phase of the annotation process the Text Annotator component forms a JavaScript Object Notation (JSON) description that defines the created metadata, which is used for the content search and recommendation.

4.2 Domain Specific Concepts

The domain-specific product ontology - Concept Design Ontology (COnDO) has been developed to facilitate the designer's creative abilities whilst managing content metadata and supporting the dynamic personalised indexing and search of design content looking for associations and analogies. It is a mean of compensating for the quality and general nature of DBpedia datasets, which are used by the semantic annotation tool previously discussed.

The design ontology is represented as an extendable set of core classes: at the centre of the top level nodes of the ontology are *Product*, *Person*, and *Content,* as well as *DesignProject* and *DesignTeam* classes (see Figure 7). The semantic network of five classes interconnected with a set of object properties is defined to represent both personal and collaborative aspects of the designers' work, connecting the user as both designer and end user, product under design, and the related design content associated with the product. The class content represents the associated resources (documents, sketches, images, videos, etc.) used or created to facilitate the conceptualization of the product.

The model of product class in the COnDO ontology is based on the Offenbach theory of product language [30] and is defined to attain a common vision through the set of ontological concepts, allowing the product to be described from different points of view, such as the domain of the product being designed (e.g. web, fashion, kitchen-ware or consumer electronics), deployment technology, ergonomic, economic, and ecological properties, and emotional response and associations created while interacting with product (e.g. historical aspects, style, cold, warm, aggressive). The design ontology is released as open source software and can be downloaded from the GitHub repository[1] for further investigation and reuse.

[1] https://github.com/OntoRep/COnCEPT

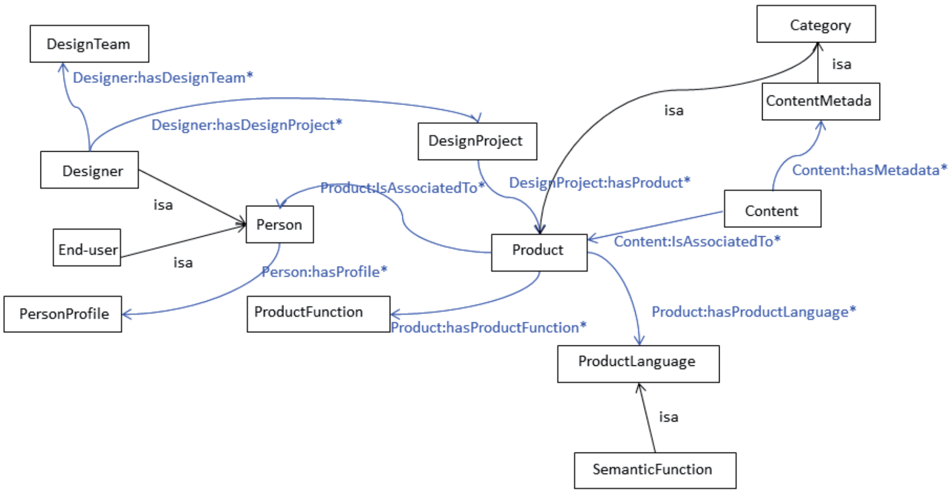


FIGURE 7: The top-level classes of design ontology.

The reuse of the pre-defined domain specific ontology is often restricted by its static nature. Thus, functions are provided to enable the designer to customise i.e. add, rename or remove ontological concepts as a part of the annotation process.

In addition, several mechanisms have been developed to ensure the customisability and usability of the proposed COnDO design ontology to better serve the needs of different designers, such as relevant ontological concepts being suggested (highlighted) to designer when the content is uploaded (as visualised in Figure 8).

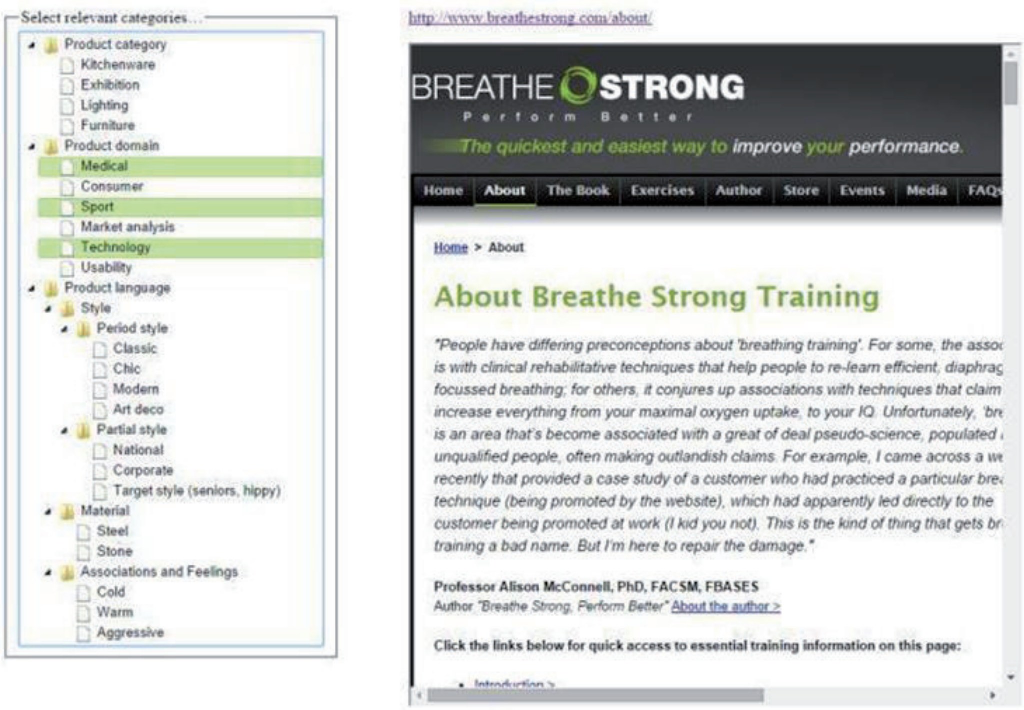


FIGURE 8: Working with content and design ontology: three concepts are suggested to include into the metadata as most relevant to the content of web page.

The ontology management component analyses received content and attempts to deduce whether it fits certain categories defined by the COnDO ontology. If matching categories are discovered, a list of relevant categories is returned to the Annotator component. This process is facilitated by DBpedia Lookup service. The method is based on the calculation of the semantic similarity of the semantically enriched concept in the ontology, with keywords being extracted from the design content during the content upload process

4.3 Search and Recommendation

The objective of the search functionality is to provide more relevant results to the designer based on the current project. The semantic search service utilizes the Apache ElasticSearch [31, 32] component to manage content metadata and to implement search functions. Semantically enriched metadata, as well as content items, are stored to MongoDB that is part of the ElasticSearch toolkit. The Apache Lucine engine is used to accomplish the search functions over JSON metadata in local database. In the indexing process, every field of JSON metadata is indexed and semantic weightings of metadata are also taken into account.

The recommendations of relevant content is performed by comparing enriched keywords provided the by designers, or derived from the analysis of documents and images with semantic metadata describing the uploaded content. The utilized matching method also considers the weighted values that indicate the relevancy of the metadata. Relevant content is recommended for the user based on the comparison analysis between enriched entities data and uploaded content metadata using classical Information Retrieval vector-space model [33].

In the case of searching web-based resources, the semantically enriched keywords provided by the designer or extracted from material used in the design (e.g. the brief or sketch) are passed to the search engines leveraging various open APIs (e.g. Google, Flickr, V&A museum, etc.). The results from both searches (local- and web-based repositories) are presented to the designer. The presented content can be further filtered and organised by the designer according to the concepts of the design ontology.

5. EVALUATION RESULTS

The semantic tool aims at supporting product designers in managing vast repositories of content in the course of design conceptualization work. Considering the demanding nature of the user group, we believe that usability and the perceived usefulness are the most important characteristics to be assessed in the early prototype version. These criteria can be further interpreted in more practical, measurable attributes, such as efficiency; how effectively the user can complete the tasks; emotional response; system feedback or how well the user is informed about what is going on; and consistency across the entire application including dialog logic and other similar applications existing in this domain.

Several methods have been established to evaluate software system usability. They can be classified into empirical methods, including collecting user data, and analytical methods, which use other means to collect usability related measurements. Empirical methods always involve end user representatives working on typical tasks using the system or prototype being tested [8]. Analytical methods are usually validated by empirical methods. The ‘perceived usefulness’ and ‘perceived ease of use’ metrics are related to usability, and are the one of the main drivers for acceptance of technology by the user [9]. Perceived usefulness as a scale is measured using the following criteria: working more quickly, job performance, increased productivity, effectiveness, and making the task easier.

The testing group containing 12[2] participants was constructed as a mix of end-users with diverse expertise in the areas of product design, UI/UX experts and business.

2 https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/

The evaluation was supported by constructing an evaluation scenario related to the conceptualization of a new ‘smart sport jacket’. Each participant was asked to perform various tasks, such as working with the design brief and other material, sketching and testing the design ontology, while inspecting the suggested content metadata. Moreover, test-users were encouraged to experiment with the tool using their own material (documents, images, web-pages, etc.). Furthermore, qualitative feedback related to performance issues experienced, desired functionalities and preferences regarding the maintenance of knowledge models (crowdsourcing vs. original ontologies) was queried and recorded. The assessment questions were built around three fundamental issues contributing to the usability and user experience: fluency and ease of use, experience and ‘liking’, and the position of technology in human action. The quantitative assessment questions and the obtained results are presented in Table 2 and Figure 9 respectively.

Q.	Feedback (5 rating levels, from excellent to poor, 5-1)
1	How easy it was to learn how to use the toolset?
2	Did you find the automatically suggested (metadata) keywords appropriate?
3	The “select category” functionality provides the ability to supply own content metadata. Did you find this functionality useful?
4	Did you find the structure of category tree logical. What would you change?
5	How useful did you find the content recommendation? Did you find design-brief and sketching apps functionality interesting, inspiring?
6	Do you think that such toolset would improve the management of your content? If, so, how much?
7	Would you like to have such toolset as part of your design environment suite?
8	How would you rate your overall experience with the toolset?

TABLE 2: Assessment questions.

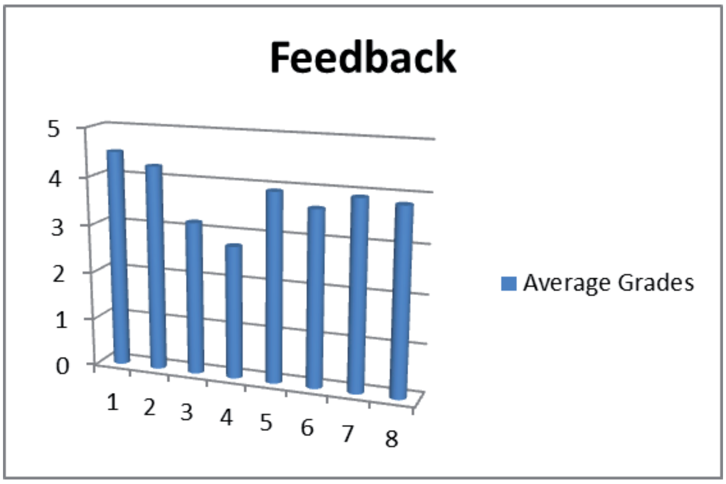


FIGURE 9: Evaluation results.

The quantitative evaluation results were positive. In particular, questions 1 and 2 scored an average grade of 4 or higher. Questions 5, 7 and 8 also received high average grades. This indicates that the respondents perceived the functionality of the tool as easy to learn, useful and inspiring. Moreover, most of the respondents indicated that they would like to have tools as part of their design environment suite.

Further analysis of the answers reveals that questions 3 and 4 received an average grade below than 3.5. This indicates that while the ontological design concepts were found to be useful, the provided category view was not seen as entirely logical for everyone. Some participants suggested simplifying the initial version of the design ontology to a basic structure as a start point.

This didn't surprise us. In fact, the analysis of the answers provided for the qualitative questions indicates that, in general, respondents prefer crowdsourcing and adding their own categories rather than using a default set of ontological categories.

The respondents also proposed some additional features that could improve the usefulness of the toolset. For example, the approach should better indicate how documents are related to each other and enable adding free-text comments and notes to content items. In addition, graphical views that summarize the available information contained by the content repository would enhance the user experience. Finally, more explicit links to information resources such as university libraries and e-book or article/magazine databases were requested, especially by respondents' professional designers.

6. CONCLUSION

This paper has provided a detailed technical description of a new semantic toolset which aims to support designers with the management of various heterogeneous content created while working on the conceptualization of new products. The software uses an advanced semantic and visual search engine to create a unique, intuitive software application which automatically generates content based on text or visual imagery.

It was demonstrated that knowledge extraction tools have the potential to support designers in knowledge exploration tasks. The advances of web based multimedia repositories and access tools, combined with recent developments in information extraction technology used to, for example, analyse design briefs or the result of brainstorming sessions, can bring real benefit to product designers by providing the means to bring associations stimulating creativity, or to facilitate the development of various mood boards, as well as to ease the access, filtering, selection, interconnection and presentation of project related information.

Considering that the target user group requires a seamless, intuitive and easy to use technology, the challenge for the developers is to create a "knowledge management interface" that can be integrated into a set of design tools, and which is automated as much as possible while keeping the technology "in control". The user may add or delete metadata or select one image over another, and the software is able to use this information to prioritise searches and present new information to the user as efficiently as possible. The focus is on the content generated rather than the 'interface' in its traditional meaning. As far as the end user is concerned, the system is performing magic by presenting new content based on the initial design brief or sketches. As the designer interacts with the software, it should become 'smarter', returning more relevant content as it learns the user's preferences.

The system must also allow for a different way to manage search results. Search algorithms are conventionally judged on how accurately they return information. However, accuracy is not necessarily the right criteria to apply. In this case, the software may be looking for associations and analogies. To some extent, the user may only know what they are looking for when they have found it. The user is relying on making connections to trigger ideas. This might be seen as a different type of uncertainty principle, in which the more certain a result is, the less lightly it is to stimulate new ideas. In contrast, the more uncertain the result the more possibilities there may be to make new connections.

Based on the evaluation results, it can be concluded that the toolset was positively perceived by the assessment participants taking part in the evaluation of the software. The evaluation provided a good opportunity for designers to participate and contribute to the development process. Further research work will concentrate on considering some of the deficiencies highlighted during the assessment. Future studies will carefully consider how to best exploit the full potential of the COnDO design ontology, including leveraging it for more efficient content grouping and presentation. A crowdsourcing approach was perceived positively by designers. This supports a starting point for further study of the importance of semi-automatic approaches to be supported by technology. Conceptual design of the product and the methods of organizing knowledge are extremely personal since the creation of products is strongly dependent on the creators and their criteria in decision-making.

7. ACKNOWLEDGEMENTS

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