Designing for Social Configurations: *Pattern Languages to Inform the Design of Ubiquitous Computing*

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In this paper we present our approach for informing the design of ubiquitous computing by using pattern languages of human practice. By linking ethnography and design, this approach makes it possible to tackle the social dimension of ubiquitous computing in the design processes. Adding to the existing research on patterns of human practice for design, we solidify the methodology for creating pattern language by identifying its links with grounded theory and action research and, via an example of a navigation support system for frontline firefighters, showing how a pattern language becomes part of the design process. Reflecting on our work, we conclude that the pattern language approach provides a framework to design for existing practice and helps to reflect the impact of novel computing artifacts.

Keywords – Pattern Language, Ubiquitous Computing, Ethnography, Firefighting.

Relevance to Design Practice – This research supports designers in handling the social dimension of ubiquitous computing systems with a methodological framework that fuses ethnography and design. Designers gain methodological grounding on how to capture human practice in pattern languages, supported by one particular case of how a pattern language supports the design process.

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Introduction

For human-computer interaction designers ubiquitous computing poses an extended set of challenges. Ubiquitous computing, as envisioned by Weiser (1991), provides a future vision of computing. Weiser pictures a world in which the human being encounters the world mediated by a large number of context-aware, embedded computers that fade away from the users' awareness. In contrast to computers used for personal use or office work, ubiquitous computing is envisioned to become an integral part of life by weaving computers into "the fabrics of everyday life" (Weiser, 1991, p. 66).

Today, twenty years after Weiser's publication, his work remains central to the vision of computing. In a recent publication on the future of interactive computing, the "ubiquity era" of computing in 2020 and beyond is characterized by "thousands of computers per user" (Harper, Rodden, Rogers, & Sellen, 2008, p. 15). Also today, ubiquitous computing has already come, at least partly, to the world. In today's reality, however, ubiquitous computing solutions appear less integrated, not as seamless and context-aware as Weiser imagined. Instead, ubiquitous computing is confronted with the "messiness of everyday life" (Bell & Dourish, 2007, p. 133).

Embedded and networked computers that are closely interwoven with human life increasingly require designers to focus on the social dimensions of computing systems. The appropriation of computing technology becomes a central concern, as "users, not designers, create and communicate meaning" (Dourish, 2001, p. 170). For Harper et al. (2008) "the bottom line is that computer technologies are not neutral—they are laden with human, cultural and social values" (p. 57).

This understanding impacts the epistemology and methodology of the research and design of human-computer interaction (HCI): it "requires HCI to shift its epistemological constraints away from their psychological roots towards other approaches […] where conceptual sensitivity to meaning, purpose, and desire is possible" (Harper et al., 2008, p. 77). Design processes need to comprise "reflective thought and conceptual analysis drawing on other disciplines" (Harper et al., 2008, p. 59). Harrison, Tatar, and Sengers (2007) identify a 'situated perspective' research paradigm in HCI for which the main concern of research is no longer to optimize the information flow between the user and computer, nor is the user's behavior modeled as a cognitive machine. Instead, users need to be understood within the larger scope of their respective contexts. Suchman (2007) describes the users' context as a wide configuration of agencies that requires researchers "to expand the frame, to metaphorically zoom out to a wider view that at once acknowledges the magic of

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the effects created while explicating the hidden labors and unruly contingencies" (pp. 283-284). In a nutshell, designers need to understand "what it means for a system to be 'good' in a particular context" (Harrison et al., 2007).

As one way of dealing with this task, we adopt the concept of Alexander (1964, 1979, 1999, 2002a, 2002b, 2009) and present our approach for using patterns of human practice as a means to make ethnography available for the design of ubiquitous computing artifacts. We start out by discussing the original concepts of Alexander and the adaptations of his work. Adding to that body of existing work, we discuss methodological concerns and provide a design case, in which the approach supported the design of an ubiquitous computing navigation support system for frontline firefighters.

Pattern Languages to Design for Human Practice

Alexander's Approach

Alexander (1964, 1979, 1999, 2002a, 2002b, 2009), as architect and researcher, has studied the interaction between human activity and designed artifacts and spaces. Alexander's interest is close to the one of Harrison et al. (1999); he wants to answer the question "Under what circumstances is the environment good?" (p. 74). Instead of simply designing buildings, Alexander aims to design overall configurations that are compatible with and beneficial for human life. In a recent letter, Alexander (2009) summarizes his concept of design:

> My fundamental proposition is […] that our environment, our built world, must originate with the ideas and feelings and relationships that bring society to life. We need to construct our environment in such a way that the environment itself—its structure, its relationships, its internal configurations—must always derive from the living structure of society of human action […] The environment will come to life for us if, and only if, it is build from generating relationships inherent in the acts of our daily life. The more we are able to rehearse our social and psychological relationships and reinforce them, the more we will be comfortable, at ease and whole within the fabric of all that we have made for ourselves. […] Logically, this is a very simple scheme, we need to access and reckon up the human and physical relationships on which we thrive, then we need to construct the physical relationships which, when built into the fabric of our environment, will nourish our social and emotional lives. (00:27:06ff)

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To understand existing configurations, Alexander proposes the concept of pattern languages. He argues that "every place is given its character by certain patterns of events that keep on happening there" (1979, p. 55) and that these "patterns of events are always interlocked with certain geometric patterns in the space" (1979, p. 75). Each pattern "is a rule which describes a type of strong center that is likely to be needed, on a recurring basis, throughout a particular environment" (2002b, p. 345). A pattern language is a collection of patterns that describes a social configuration. Each pattern therefore "not only describes a recurring center, but also describes a relation between other generic centers" (2002b, p. 345). Such centers, "to be living centers, must be beautifully adapted to one another within the whole: each must fit the other, each must contribute to the others, and […] must form a coherent and harmonious whole" (2002b, p. 3). The 'Quality Without a Name' that Alexander seeks to capture in pattern languages "makes us feel alive when we experience it" (2002a: 36). It is characterized by a "freedom from inner contradictions" (1979, p. 26) and occurs "when things are going well, when we are having a good time, or when we are experiencing joy or sorrow—when we experience the real" (2002a, p. 37).

To evolve existing configurations by design, Alexander (2002b) proposes a process that has to be "smooth", as he paraphrases it, "naturally", "without effort", the transformation is "working under the surface as part of other known processes" (p. 52). The design process should be iterative, gradually molding the new shape. "The idea is that a structure-preserving process on the one hand transforms and preserves structure and on the other hand the idea is that this structure-preserving transformation then also enhances the whole" (p. 255). Alexander characterizes this design process as careful and personal, a humane process between designers and users that is "not guided by the grasp for a goal, but guided by the minute-to-minute necessity of caring, dynamically, for the feelings and well-being of another" (p. 9) .

Alexander's design approach, at its core, brings together human practice and design and thereby integrates the situated aspects that have been identified to be vitally important for the design of tomorrow's ubiquitous computing solutions, given their embeddedness in space and their intertwinement with social life. Consequently, the question arises if and how interaction designers can make use of his architectural concepts for the design of ubiquitous computing artifacts.

Adaptations of Alexander's Approach

In the field of architecture, Alexander's work has been controversial. On the one hand, architects argue that Alexander's pattern language does not work for designing buildings when mechanically applied as a structured plan (Campbell, 2009, 01:07:30). Pundits diagnose methodological shortcomings in Alexander's process of pattern creation (Saunders, 2002, p. 4). On the other hand, architects propose pattern languages to build catalogs of technical drawings to support their work (Silva & Paraizo, 2008). Here, the focus and discussion is on producing shareable design solutions.

Rather than focusing on design solutions, the urban planning community also successfully applies the pattern language approach as a way of analyzing human practice and discussing the impact of design on this practice. Using pattern approaches, architects rationalize the design of public places in metropolitan cities as well as in small towns by studying the life of the citizens (Hester, 1993; Whyte, 2001). These approaches of using pattern languages are especially relevant for this work, given their focus on understanding social configurations and local situations, an aspect that is also emphasized by Alexander, especially in his later work (2002b, p. 355; 2005, pp. 127-131).

In the field of computer science, Alexander's work has been influential both in software engineering (Gamma, Helm, Johnson, & Vlissides, 1995) and in interaction design (Borchers, 2001; Tidwell, 1999). While these adaptations have shown to be beneficial to practitioners and are broadly used (Kruschitz & Hitz, 2010), they are limited to the concept of sharable design solutions in pattern format and do not make use of Alexander's overall concept of designing social configurations. Other adaptations in computer science make, however, use of this idea and propose pattern approaches that interweave ethnography with design.

Erickson (2000a, 2000b) suggests the use of pattern languages as a 'Lingua Franca' in design processes for computing systems, addressing the need to design systems in interdisciplinary teams that integrate well in existing workplaces. Using patterns, Erickson (2000a) seeks to design settings that fulfill the 'Quality Without a Name', "a shorthand for systems which really 'work' for people in all of the many meanings of that phrase" (p. 361). He calls for site-specific pattern languages as a first step towards a more general lingua franca in the long term. These patterns and their relationships should not be used to reject or approve design aspects, but instead "can be used as a language for discussing changes and reflecting on their possible impacts, both in terms of the activities of the organization, and in terms of the qualities of work life which its members value" (p. 366). Inspired by Erickson's proposal, Martin, Rouncefield, and Sommerville (2002) look for patterns in human practice of cooperative interaction in governmental work environments. Martin et al., however, do not work on a coherent pattern language, as envisioned by Erickson.

Crabtree, Hemmings, and Rodden (2002) present patterns to support the design of future computing technologies for the home, where standard measurements, originally developed for office environments, do not, or only partly, apply and where ethnography should inspire future designs. By using video ethnography and thick descriptions (Geertz, 1973), the authors capture people's activities in their homes and identify patterns in their actions. Patterns of social action become a means "for structuring and presenting ethnographic fieldwork" (Crabtree et al., 2002, p. 265). In their work, the authors provide an exemplary pattern that describes the activities centered at the kitchen table as a design space for future technologies. Crabtree et al. conclude that patterns of technology use in the home "make unsupported use practices available to the design of future technological arrangements in place" (p. 269).

While the existing work describes patterns and pattern languages as a means to make human practice available for design, it says surprisingly little about how to construct such pattern language. A sound methodology is, however, important for the approach to gain a solid grounding and to produce knowledge beyond mere rules of thumb. In a panel discussion on patterns for interaction design, Sutcliffe states that "[t]he key problem for patterns is to develop a sound theory of abstraction" (Borchers & Thomas, 2001). Another open point in the existing work is the lack of examples that show the benefit of the approach. In the works described above, only one pattern or a small set is used as an example, leaving open the role of pattern languages and the meaning of structure-preserving transformations.

In the following paper we will therefore focus on both of these two aspects, the methodological question of how to construct a pattern language on the one hand, and the practical relevance of a pattern language approach in a design case, on the other.

Constructing a Pattern Language

Alexander's Methods

Alexander (1964, 1979, 2002a, 2004, 2005) describes his methods for identifying patterns and creating pattern languages in a number of publications. To provide an overview, we summarize the following six aspects of his approach.

First, Alexander's (1964) goal is to create a description of existing social configurations. In contrast to applying abstract, pre-defined theories for design, "conceptual dogmas" (p. 70) as he denounces them, Alexander (1979, p. 348) aims to produce sharable knowledge of existing configurations that supports both professional and laymen designers in making design decisions.

Second, the process of pattern discovery itself takes time and "must always start with observation" (p. 254). This observation is a personal and situated activity. Alexander (1979) argues: "Suppose we are in a place. We have a general sense that something is 'right' there; something is working; something feels good: and we want to identify this 'something' concretely so that we can share it with someone else, and use it over and over again" (p. 249). Alexander asks the designer to develop empathy with his users. "The essential technique in the observation […] is to allow the feelings to generate themselves, inside you. You have to say, 'What would I do if I were one of the people living here, what would it be like for me?'" (2002b, p. 352).

Third, Alexander (1979) compares specific configurations, to better identify the problem and solution offered in a particular space. He suggests looking at a number of instances of a certain space and comparing those that feel good with those that do not, in order to extract commonalities and to understand the underlying problem (pp. 256-257). He, for instance, shows people photographs of two buildings, two streets, etc. and asks questions such as: "Which of the two seems to generate a greater feeling of life in me? Which of the two makes me more aware of my own life?" (2002a, p. 355) The answers support Alexander in looking for similarities in the positive examples.

Fourth, once identified, Alexander (1977) suggests describing problems as a system of contradicting forces that the pattern helps to resolve. The pattern 'Alcoves' (p. 832) that describes the need for alcoves in living rooms, for example, resolves the force of individual hobbies of household members that require them leaving their stuff safely at defined places, the force to keep shared places tidy for visitors and respectful of other household members and the force of household members to be together while pursuing their individual activities. Forces can be specified as a configuration of other, related patterns. Relating the patterns in this way links them up into a pattern language.

Fifth, Alexander works with the experience of users and their imaginations. He directly asks people for the places of their dreams (2002b, p. 355; 2004, p. 250). He states, for example: "I took André and Anna to the site one day, and asked them to visualize, to remember the most wonderful house they had ever known, the place which made them most comfortable, and where—if they were there now—would make them feel most comfortable" (2002b, p. 355).

Sixth, especially in his later work, Alexander proposes the use of prototypes, as a means to iteratively and in collaboration with users create future designs and learn about the relevant forces in a given context. He introduces prototypes to monitor the feelings that they evoke in-situ. Using paper he, for example, simulates beds, the experience of a public bench or the shape of columns (2002b, p. 611; 2004, p. 126; 2005, p. 355). Alexander highlights this process of design as a collaboration with users that forms a collective vision of the future (2005, p. 257ff).

A Pattern Language as a Grounded Theory

Transferring Alexander's methods from the context of architecture to the context of ubiquitous computing is not straightforward. His approach relies on intuitively assessing wholes from personal experiences in space. For ubiquitous computing systems, the configuration could be highly distributed; its complexity may be impossible to be captured in static visual form. Comparisons and questions are therefore less obvious to identify and, most importantly, often cannot rely on past experience. Different from buildings, users may have no previous experience with a particular technology that they could refer to. Consequently, Alexander's methods provide an overall concept but require refinement. To increase the applicability of the approach, we therefore relate it to other, widely applied methodologies.

Abstractly, Alexander's creation of a pattern language can be framed as an instance of research, where an initial interest, in this case the quality of life in designed spaces, leads to a theory in a bottom-up process. From this perspective, Alexander's work appears similar to the methodological considerations by Glaser and Strauss (1965, 1967), two sociologist, who, when confronted with the task of studying the social aspects of dying and death in hospitals, coined 'grounded theory' as a method for developing theories that hold relevance not only for scientists but also for practitioners. In grounded theory, the lens of research is not defined a priori; instead, it evolves in the course of the study, grounded in and targeted for the phenomenon at hand. Instead of testing predefined hypotheses based on existing theories, Glaser and Strauss look for patterns in ethnographic data that they collect through observations and interviews. For their study of dying patients they argue that "discernable patterns of interaction occur predictably, or at least non-fortuitously, during the process of hospitalized dying, and that explicit knowledge of these patterns would help the medical staff in its care of dying patients" (1965, p. ix).

A grounded theory comprises the elements of categories, properties and hypotheses. Glaser and Strauss (1967, p. 36) define a category as a conceptual element of the theory that describes an abstract concept that explains a certain type of behavior. A property describes an aspect or element of a category. A hypothesis, finally, suggests a relation between the different categories.

Practically, grounded theory methods can be summarized as follows. In a number of iterations, the researcher collects empirical data, "theoretical sampling" as Glaser and Strauss (1967, p. 45) named the process. The data resulting from theoretical sampling is first coded and then analyzed using the "constant comparative method" (1967, p. 101). The constant comparative method is described as a four step process (pp. 105-113). In step one, "comparing incidents applicable to each category", the researcher identifies incidents in the data, compares them and builds categories. In step two, "integrating categories and their properties", the focus shifts from the comparison of individual incidents to the comparison of incidents with the already existing categories and properties. In step three, "delimiting the theory", the researcher aims at increasing the integrity of the theory. Finally, in step four, "writing theory", the researcher, convinced of the saturation of the theoretical framework, writes up the theory.

Strauss and Corbin (1990, p. 26) call for "theoretical sensitivity", a personal quality of the researcher required to create "awareness of the subtleties of meaning of data" (Strauss

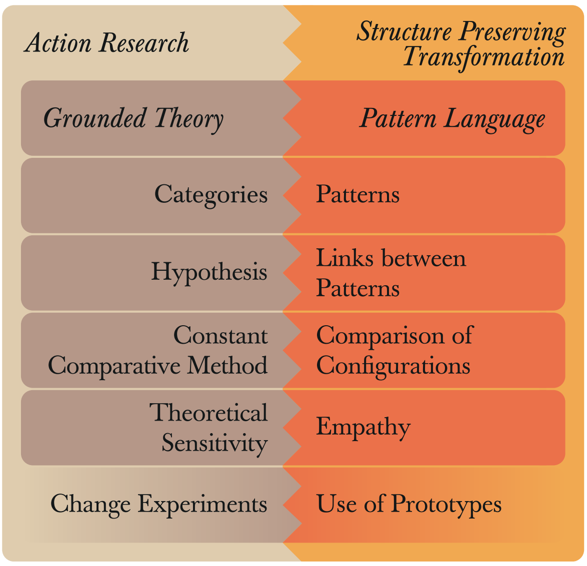

Figure 1. Alexander's concepts of structure preserving transformations and pattern languages transposed to action research and grounded theory.

& Corbin, 1990, p. 41). This sensitivity can be gained through both professional and personal experience that builds an empathic bridge to the context of the study.

Comparing grounded theory with Alexander's pattern language reveals the parallels of the approaches (Figure 1). Both methods share the motivation of refraining from imposing abstract, pre-defined theories and evolve theories that hold relevance for the subjects of the study bottom-up from empirical data. Both methods derive patterns by comparing phenomena. Alexander's patterns emerge from observation and categorization of human behavior, as do the categories in grounded theory. For both approaches links between the patterns, which lead to hypotheses for grounded theory, are important to form the overall theory. Finally, Alexander's concept of making active use of human intuition finds its parallel in the call for theoretical sensitivity. Given these parallels in the motivations, methods and structures we argue that Alexander's concept of pattern languages can indeed be understood as an instance of a grounded theory with the general theme being the quality of living in towns and buildings.

Grounded theory, however, does not include a theme of design and the idea that changes in practice by prototypical artifacts can be used to improve understanding. Here, the concept of action research (Lewin, 1946) provides a theoretical framework. The various action research approaches share the assumption that "human organizations, as a context that interacts with information technologies, can only be understood as whole entities" (Richard Baskerville, 1999, p. Part II). In action research, the researcher becomes part of a team that introduces changes, such as prototypes (Wood-Harper, Antill, & Avison, 1985, pp. 121-122), into existing practice and iteratively learns about the overall configuration from the effects that these changes produce. Putting action research and grounded theory into relation, Baskerville and Pries-Heje (1999) show that grounded theory methods can bring rigor and methodological soundness to action research. Accordingly, Alexander's overall design approach can be understood as an instance of action research, given his focus on overall configurations, in which the pattern language concept serves as a grounded theory that also gains samples from action research experiments (see Figure 1).

The benefit of this transposition of Alexander's methods is twofold. First, grounded theory has been widely applied and provides a hands-on methodological framework for designers' work. Second, the methods have been discussed and acknowledged by scientific communities. They help to rationalize the pattern language approach and support the creation of new knowledge.

Designing Computing Based on Frontline Firefighting Practice

Ubiquitous Computing for Frontline Firefighters

Making a case for the pattern language approach, we present an example in which we were confronted with the task of designing computing for frontline firefighters, a work setting in which to this day, despite ongoing research efforts, almost no computing support exists.

The work context on the frontline of an intervention poses a complex set of requirements. Most researchers avoid the constraints of the frontline by focusing on the part of firefighting that takes place in relatively safe and less restrictive environments (e.g. Landgren & Nulden, 2007). The little work that specifically focuses on technology for firefighting on the frontline takes out certain aspects of firefighting practice but does not consider overall firefighting practice such as the collaborative nature of the job (e.g. Naghsh & Roast, 2008)[1]. Firefighting frontline practice is, however, very likely to be negatively affected by systems that do not take into account the full complexity of the task.

Firefighting is a craft that is based on long experience, with firefighting as a profession dating back to ancient Rome and Caesar Augustus (Kenlon, 2008). Preserving the identity and culture of firefighting is crucial to ensuring that firefighters continue to be willing to put their lives at risk for the benefit of the general public. Today, firefighters know how to deal with fire and in most cases do so safely. The focus of the work on the frontline is on rescuing people and extinguishing fire, activities that are unlikely to be replaced by computing. Therefore, supportive technology has to closely match the existing practice and needs to be trusted. A structure preserving process, as suggested by Alexander, is therefore essential when designing ubiquitous computing support for frontline firefighting.

Field Work

Over a period of three years, we have conducted a variety of workshops in the context of two projects with firefighters from Germany and France and gained a thorough insight into frontline practice. The hazardous conditions on the frontline in real interventions limit access for the purpose of research. Consequently, there are only limited scientific accounts of this work. To approach the field, we therefore chose a multifold approach, linking a variety of simulated interventions in professional training settings with accounts of real interventions.

In the first project, workshops took place at the training center and fire station in St. Denis with firefighters from Paris. In the second project, workshops were conducted with the firefighters of Cologne, Germany at the firefighters' local fire station, and at Europe's most advanced firefighting training facility, the State Fire Service Institute of North-Rhine-Westphalia in Münster, Germany. It is possible at this facility to simulate interventions close to real world conditions (Figure 2). During the workshops at the fire station, regular operations continued and firefighters sometimes had to leave for incoming alarm calls and returned to the workshop after finishing their mission, drawing a close connection between real-world incidents and what was discussed in the workshops. In combination, both firefighting organizations provided a broad picture of firefighting practice since their cultures and procedures vary, as do the tools in use.

Grouped into the sections of ethnographic studies in our research that aim to understand firefighting from an observer's perspective are empathic exercises that focused on the hands-on experience of firefighting practice, and activities focused on introducing ubiquitous computing into frontline practice. An overview of the studies which were conducted is presented below.

Ethnographic Studies: Observing Firefighting Frontline Practice

In St. Denis, intervention exercises made it possible to observe firefighters who, with their masks covered, performed simulated reconnaissance missions in standard building structures. The exercises took place in a fully equipped maisonette apartment of a training facility as well as in the basement of the facility featuring a heating installation (Figure 3, left).

With the idea of learning about the practice from the equipment used, we interviewed firefighters about assigned and personally chosen tools (Denef, Keyson, & Oppermann, 2009). We took stock of the tools in the pockets of the protective clothing of an entire brigade that was ready to be used in case of an incoming alarm and asked firefighters about the set of tools that they personally use (Figure 3, right).

Other, more informal investigations and interviews took place at a firehouse of the Cologne firefighters and at the Fire Service Institute. During and after the workshops firefighters informally explained their daily routines, the work schedule, and provided anecdotal stories about past incidents and related them to the workshop experiences.

Adding to the work with the two focal firefighting organizations, we observed and interviewed firefighters working at a large chemical plant that has its own permanent crew of firefighters, at a container port terminal with facilities for the decontamination of dangerous goods containers and during an exercise in a subway system.

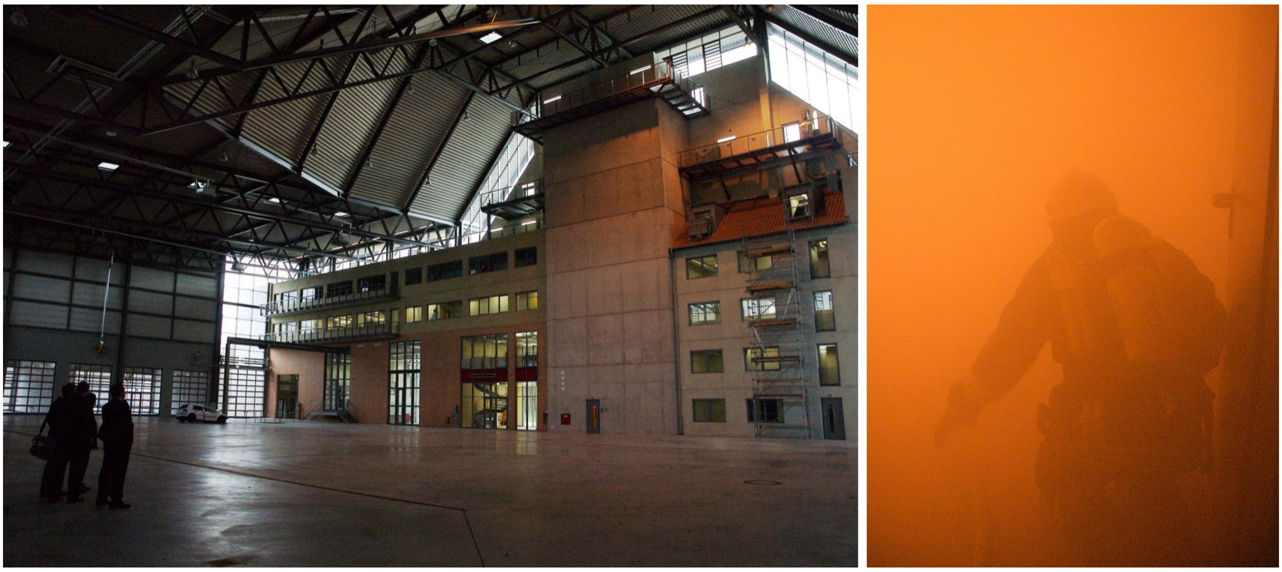

Figure 2. Training facility (left) and simulated intervention (right) at the State Fire Service Institute of North-Rhine-Westphalia, Münster.

Figure 3. Observing frontline practice in a basement mission (left) and interviews on personal tools (right).

Empathic Exercises: Experiencing Frontline Work

Equipped with fire-protective clothes, helmets and breathing apparatuses, our research team took part in different exercises at the training premises in St. Denise. The exercises were set-up for firefighters with varying levels of experience and the captains thoroughly described every procedure. A cargo container set on fire showed how fire propagates, how to effectively extinguish fire and how to deal with smoke in enclosed spaces (Figure 4, left). A fire, lit up in a tunnel, allowed training in navigational skills in closed, heated environments. A gas-powered fire simulator demonstrated the distribution and dynamics of heat in a burning kitchen (Denef, Ramirez, Dyrks, & Stevens, 2008).

At the Fire Service Institute we simulated an entire intervention in which the first author acted as incident commander, supported by a professional commander (Dyrks, Ramirez, & Denef, 2009). Researchers and firefighters jointly performed a rescue mission in an apartment building. The exercise included the entire process of an intervention starting with an incoming alarm call. The brigade comprised a command vehicle, two pumpers, a turntable ladder and a total of 22 firemen out of which half were professionals (Figure 4, right).

In addition to learning about the different roles in an intervention, our team also joined exercises specifically focusing on frontline practice. At the Fire Service Institute, rescue exercises trained teamwork when firefighters are faced with the stress of rescuing dummy victims in rooms full of smoke. At the firehouse in Cologne, our team took professional trainings that ensure firefighters' physical fitness before using breathing apparatuses in real interventions and also participated in heat trainings where fires in a building structure permit the creation of the same thermal conditions that firefighters face in burning buildings.

Figure 4. Exercises in St. Denis with container set on fire (left) and at the Fire Service Institute simulating an entire intervention (right).

Figure 5. Wizard-of-Oz generating position data (left) for the command post display (right).

Change Experiments: Introducing Computing for the Frontline

In visions of future computing for firefighters, the commander can continuously monitor the status of the operation (Discovery Channel & Wired Magazine, 2006). Putting this vision to a test, we designed a command post system as a wizard-of-oz location tracking system that allows the commander to see the current positions of his frontline firefighters as part of an interactive, three-dimensional map of the training facility, displayed on a large touchscreen (Figure 5). We tested the system in several simulated interventions, involving two or three teams on the frontline and the incident commander (Denef et al., 2008).

We also tested a commercially available egress transmitting system that supports the tracking of lost firefighters but has not yet made its way into firefighting practice. At the Fire Service Institute firefighters used the system to support the mission of a back-up team that tries to rescue a frontline team in a scenario where the frontline team faces sudden problems and needs outside support (Figure 6).

The research with the Cologne firefighters was framed by a project that aimed at building a navigation support system for frontline firefighters based on ubiquitous computing technologies. In the vision of the project, a sensor network, deployed by the firefighters in building structures, should support their work (Ramirez, Denef, & Dyrks, 2009). In the scope of the project, we conducted several participatory design workshops in which firefighters and researchers jointly discussed and tested the novel navigation technology (Figure 7).

Creating a Pattern Language

Our understanding of the practice and the identification of patterns was an evolutionary process that continuously grew together

Figure 6. Introduction of egress transmitting system (left) and firefighter in rescue scenario (right).

Figure 7. Participatory design workshop (left) and test of in-mask feedback mechanism (right).

with the amount of empirical data while doing the research. The identification of patterns greatly benefitted from a broad variety of data, from the combination of approaches and from having insights from two different forces.

The workshops produced a large set of empirical data. Exercises were video-captured from different perspectives of the frontline teams and outside commanders. Infrared video recording helped to increase visibility in dark rooms full of smoke. Time-referenced transcripts of the video recordings as well as an integrated notation of the events, including markings for break down situations, supported the analysis. Personal notes helped to capture informal information and exercises where video recording was not an option due to hazardous conditions. Accident reports and training materials enlarged the corpus of empirical data.

Some of the patterns were already easily visible while observing the trainings. These patterns, especially the empathic exercises and personal reports of the firefighters, provided an understanding of the subtle details and social meaning of these core practices for firefighters. For other patterns, we only identified first hints when actively taking part in the actual work. Using these hints as motivators for more specific interviews or the introduction of technology, we deepened our understanding and verified or corrected our personal experiences. Other patterns were only identified first in the statements of firefighters after we introduced our technology and firefighters explained how their real practice differs from the concepts of our technology and why certain issues that became important in the experiments would have been dealt with differently in real interventions. We could then verify these patterns by taking part in exercises that followed the original procedures. These different approaches of ethnography, empathy and change, thus became relevant for each pattern in a unique combination and together supported us in identifying and saturating the patterns and the interactions within them.

Especially for the purpose of abstraction, the combination of insights from the two different forces in France and Germany was of great importance. While there were distinct differences in the detailed activities, our wider perspective enabled us to describe, on the one hand, the general principles affecting the way firefighters address a mutual problem and, on the other, the variety of ways a certain pattern could be implemented in practice. The comparable conditions under which both forces operate in burning buildings allowed us to present their solutions in the patterns side-by-side.

Our process of theoretical sampling, however, was not always as clearly planned as the above might suggest. While we designed experiments and artifacts to produce deeper insights into a specific phenomenon—such as our studies of firefighting tools, of collaboration among firefighters or of navigation practices—in other cases, a personal experience in an empathic exercise developed new insights and theoretical sensitivity that we also used as an analytical lens on our already existing empirical data. A certain statement by a firefighter, for example, previously not considered especially relevant for a pattern became important when analyzed from this new perspective.

The construction of the overall pattern language was an iterative process, during which we looked for the affinity of aspects in the practice to produce a manageable amount of patterns that are clearly distinct. Inspired by Alexander's concept that a pattern language should allow everybody to build a house, we imagined and discussed our overall language as a manual for a group of novices that were confronted with the task of fighting a fire, telling them how they needed to organize and act in order to stay safe. This scenario supported us in creating a language to be shared with other technology designers.

A Pattern Language of Frontline Firefighting

As the result of the approach which we took in our case, we present 16 patterns that describe the practice of frontline firefighting. The pattern FLUID ORDER presents the core category or theme, a meta pattern that describes a fundamental balance between strictness and openness in frontline practice. RIGID STRUCTURE, INDEPENDENT UNITS, and PROCEDURES show how firefighters divide roles and tasks. The patterns EVER-CHANGING PUZZLE, MONITORING, SHARED ESTIMATES, and TAKE GOOD CARE describe how firefighters collect and deal with information in a hazardous, dynamic environment. BIG FAMILY details the social relationship in a brigade. MULTIMODAL ACTS, HANDY MULTI TOOLS, and MASH-UP address the often-improvisational character of the physical work on the frontline. THE WAY BACK, and BACKUP TEAM provide safety solutions. EXERCISE, and LEARN BY MISTAKE finally bring means to improving and evolving frontline firefighter work.

In our pattern descriptions we link back to the empirical data by including quotes and scenario descriptions of the practices that substantiate the pattern and explain the connections between patterns in detail.[2] While we cannot fit the fully detailed patterns into this paper, we provide an overview in short summaries. Following Alexander's tradition, the pattern is identified by a capitalized title and the summaries provide a short description of a specific problem and its solution in practice.

The Patterns

FLUID ORDER: Firefighters are called when systems are out of control. They need to react quickly to prevent further harm in an ever-changing, life-threatening environment. Therefore, firefighters respond to the challenge they face in a fluid manner. They apply pre-defined structures and tactics to restore order yet are aware of the uniqueness of the incident and improvise according to the situation at-hand. The incident shapes the operation and the operation is shaped according to best practices and experience.

RIGID STRUCTURE: Firefighting operations face unknown, often chaotic situations. Nevertheless, firefighters have to act promptly and decisively. Therefore, a rigid organizing structure forms the backbone of the operation. Roles are clearly defined and visible, allowing everybody to see who is in charge at different levels. Beyond fixed roles and hierarchies, the structure serves as a means for mutual responsibility and trust.

INDEPENDENT UNITS: As a result of the extreme conditions of the environment, frontline firefighting is an isolated activity that does not allow giving detailed instructions top-down in a RIGID STRUCTURE. The perceived situation in a burning building is so eminently unique that others cannot put themselves into the position of the individual on the frontline. Therefore, small work units of two or three firefighters work very closely with each other and only receive general missions. Detailed decisions are left to the unit itself.

PROCEDURES: After their arrival on-site, firefighters have only so much time to decide what to do. The RIGID STRUCTURE distributes responsibility, yet firefighters have to act collaboratively and even as INDEPENDENT UNITS need be mutually aware of what they are doing. Therefore, firefighters rely on a set of procedures that define how to react and the next steps to take.

EVER-CHANGING PUZZLE: An incident changes continuously. As early impressions could be incorrect, following PROCEDURES appropriately requires taking emerging information into account before taking action. Therefore, firefighters continuously work on aligning chunks of information from bystanders, people in need, existing knowledge about the incident site and frontline teams to form an overall picture of the situation.

TAKE GOOD CARE: Even when following PROCEDURES, INDEPENDENT UNITS are not necessarily safe. On the one hand, the environment might radically change within bursts of a second and pose immediate threats. On the other, the actions of firefighters could lead to new life-threatening conditions. Therefore, firefighters always prepare for unfortunate things to happen and take means to prevent them. Thereby, they are prepared for the unforeseen and keep a high level of attention to their environment.

SHARED ESTIMATES: Firefighters need numeric figures to make decisions on using their equipment. However, they lack information and do not have precise measurements. Therefore, firefighters produce estimates that size up the environment and can be shared as part of the EVER-CHANGING PUZZLE.

MONITORING: Firefighters might face situations that need to be recognized when sudden changes and threats put them in danger and they need immediate help. Especially with INDEPENDENT UNITS it is difficult to ensure that emerging threats can be identified. Therefore, dedicated firefighters monitor the operation. More than a mere procedure, monitoring means caring for others and fulfilling an expected obligation.

BIG FAMILY: In a firefighting operation with a RIGID STRUCTURE, tasks and roles hold different characteristics. It is however necessary for firefighters to work jointly on an EVER-CHANGING PUZZLE and to interpret their situation and the situation of others through constant MONITORING. Therefore, firefighters form a close team in which seniors and subordinates know each other well, as in a big family. They ensure that they keep a high level of empathy for each other.

BACKUP TEAM: As INDEPENDENT UNITS, firefighters might face situations out of which they cannot lift themselves and find themselves in need of immediate outside help. Other colleagues, however, might be busy with their own tasks and therefore might not be available for quick support. Therefore, firefighters have backup teams on stand-by that are solely responsible for providing support to INDEPENDENT UNITS in trouble.

THE WAY BACK: When engaging a hazardous environment, firefighters might face difficulties they cannot solve in the limited time available to them. Therefore, firefighters always work on maintaining a return path to a safe place and mark the way that they will follow. This path also works as a means for a BACKUP TEAM to locate lost teammates.

MULTIMODAL ACTS: Working in rooms full of smoke, firefighters cannot visually grasp the environment. Therefore, firefighters use all of their senses to feel the environment around them. They rely on tactile feedback from different parts of their body. They look for visual cues, feel the temperature and listen for sounds.

MASH-UP: The frontline situation is difficult to predict and firefighters need to TAKE GOOD CARE. At the same time, INDEPENDENT UNITS are heavily loaded and are only able to carry so much equipment. Therefore, firefighters make creative use of the environment around them. They look for alternative uses of the things that they find along the way. The environment becomes a grand collection of potential tools to be mixed with existing PROCEDURES and HANDY MULTI TOOLS.

HANDY MULTI TOOLS: Firefighters frequently face problems that require special tools. INDEPENDENT UNITS can neither lift additional loads nor have the time and energy to go back to the engine for additional tools, instead they need to MASH-UP. Therefore, firefighters bring tools that can be used for different purposes and invent new ways of using the tools in combination with the environment.

EXERCISE: Firefighters do not fight fire all the time. Serious fires are rare. Firefighting missions are one-shot operations, and failures in these interventions risk lives. Therefore, firefighters need to train for a variety of aspects of their work over and over again. Exercises are designed in ways to both include PROCEDURES and expected exceptions.

LEARN BY MISTAKE: After all, in interaction with hostile and dynamic environments, mistakes are made and unfortunate things happen. PROCEDURES and EXERCISE may not incorporate all the possible exceptions that could occur. Therefore, firefighters use operations with accidents or near-accidents to reflect and improve PROCEDURES and EXERCISE and thereby to prevent future accidents.

The Pattern Language

Links between patterns form the overall language. Links indicate that a pattern provides the context for another pattern or, respectively, details the properties of another pattern. In Alexander's pattern language this hierarchy follows the level of scale, starting from pattern on towns to patterns on buildings and their elements. For the patterns presented here, such overall scale is missing and the relationships are not necessarily exclusive. More important than an absolute concept of hierarchy or an absolute concept of references is the understanding that certain patterns in firefighting frontline work appear closely related and depend on each other. Indeed, following grounded theory, the links between the patterns are not findings, but hypotheses open for further research. In this spirit, the graph of the pattern language makes visible the links between the patterns (Figure 8).

The Design of a Navigation Support System

The connection of this understanding of frontline practice with the design process becomes visible when linking the evolution of our understanding of frontline practice with the parallel evolution of design concepts for the navigation support system.

In the beginning, the project started by focusing on digital means to support frontline firefighters for THE WAY BACK. Inspired by the lifeline, a rope that firefighters use to connect to the outside, and mindful of its limitations when multiple teams work inside buildings, the first vision was to equip firefighters with a device that periodically drops beacons of a sensor network to mark their paths (Figure 9, left). The beacons should built an ad-hoc network and sense their relative position (Figure 9, right). On the way back, firefighters would make use of this sensor network by following the directional information, automatically calculated and shown on a head-mounted display. Also, the system should disclose the firefighters' positions to the commander (Figure 10). Understanding the patterns in frontline practice, we significantly revised this concept.

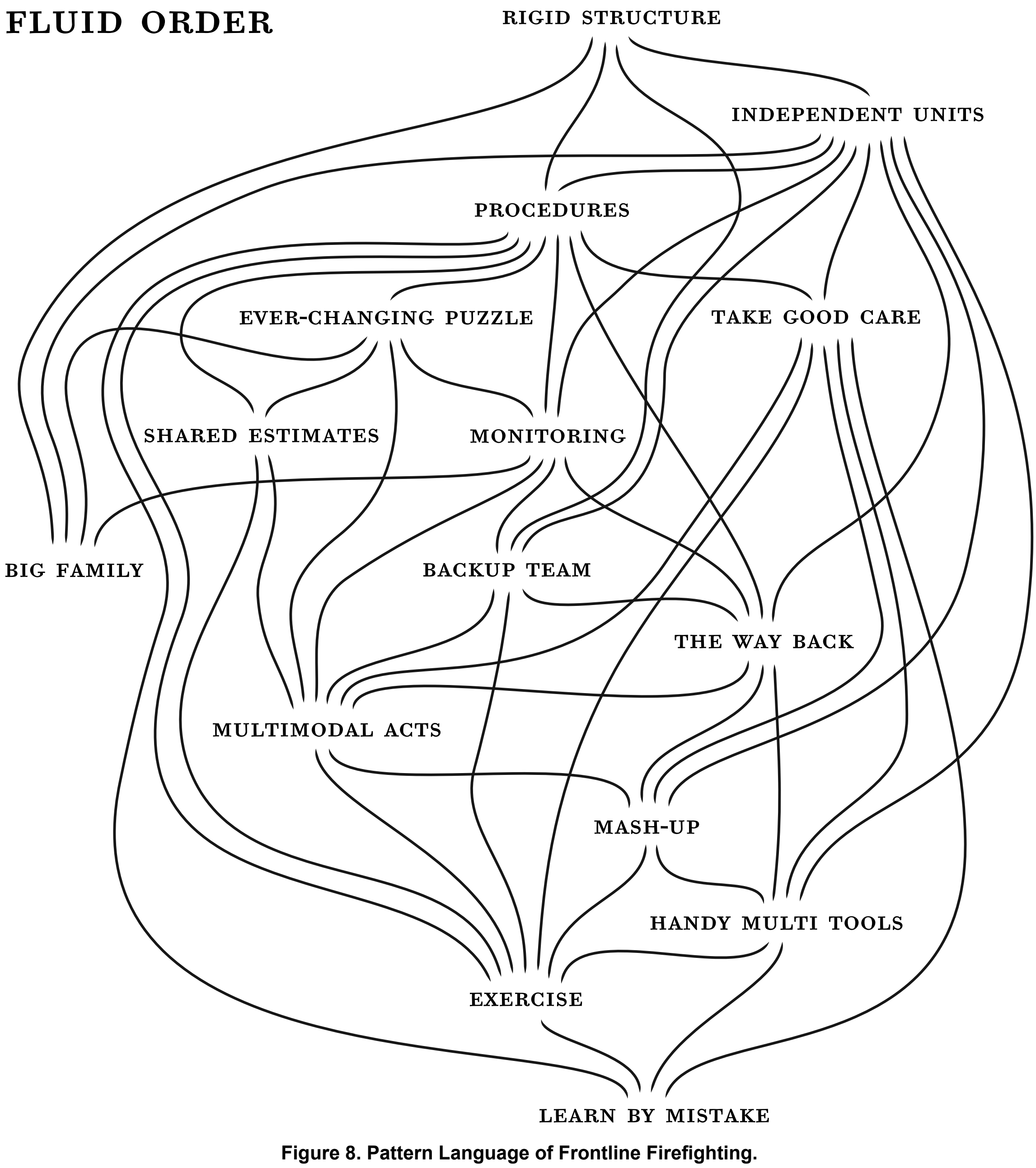

Figure 8. Pattern Language of Frontline Firefighting.

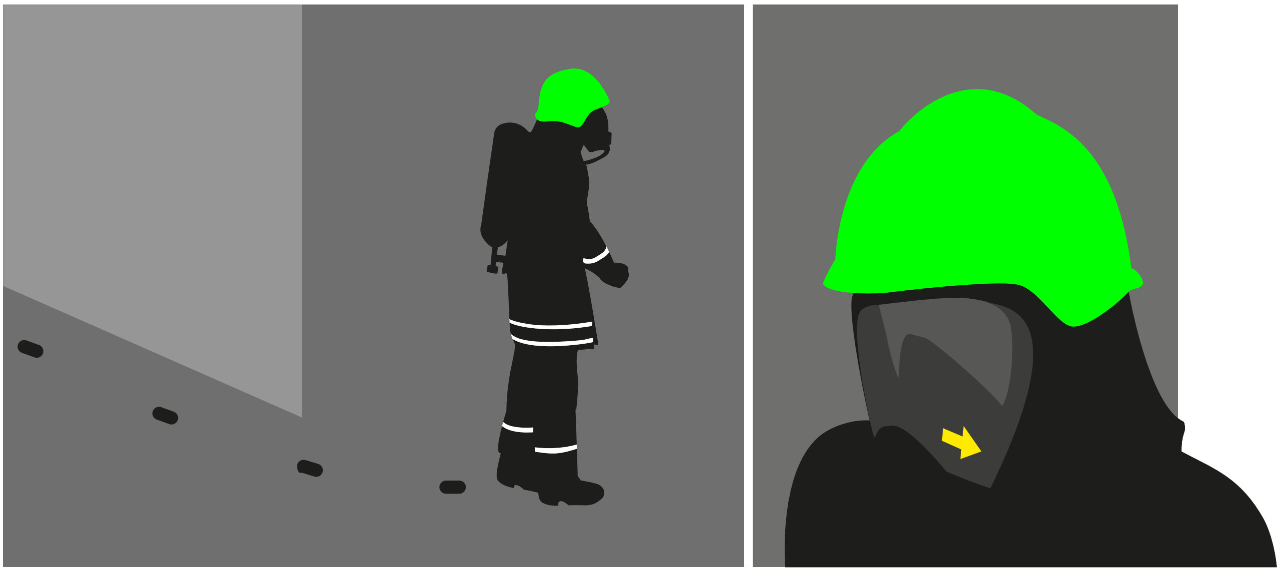

Figure 9. Navigation concept based on sensor beacons (left) and a head mounted display (right).

Our studies with the digital command post showed that new information about the context on the frontline transmitted to the outside reduces the autonomy of INDEPENDENT UNITS. More than what is currently common in MONITORING, the system allowed the commander to direct frontline firefighters. The commanders, mediated by technology, extended their range of command and the RIGID STRUCTURE to the frontline. The lower ranked frontline firefighters found themselves in conflict between the world that they experienced on-site and the guidance that they received from the outside, from a commander that they usually trusted as a member of the BIG FAMILY. Navigation in indeed based on MULTIMODAL ACTS and MASH-UP. We concluded that "rather than telling firefighters where to go we want to support them in creating their own paths" (Denef et al., 2008) and thereby decided to build on and directly support INDEPENDENT UNITS in their autonomy as INDEPENDENT UNITS: an autonomy which keeps the RIGID STRUCTURE agile and is a crucial element in maintaining FLUID ORDER (Denef et al., 2008; Denef, Keyson, & Oppermann, 2011).

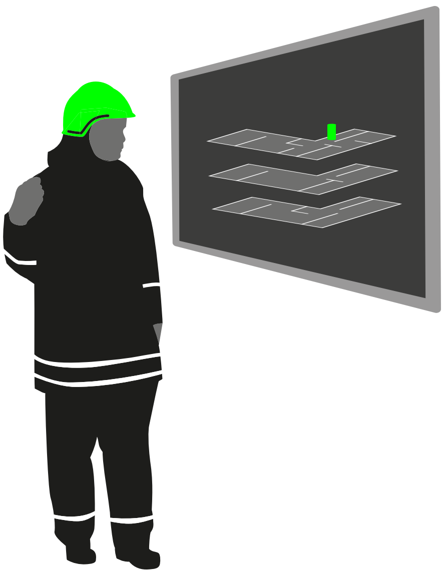

Figure 10. Command post display with live position of frontline firefighter.

In the new concept, firefighters deploy beacons manually and use them to mark spots in the environment as new points of reference, as landmarks, which help them to form a mental model of the place. Positioned manually and identified with a unique number, the beacons gain meaning and become a mutual point of reference in the EVER-CHANGING PUZZLE that can support a BACKUP TEAM seeking to find missing comrades (Figure 11). Presenting this concept to firefighters motivated them to start the second project, dedicated to the design of that system.

As a result of an empathic kick-off workshop of that project, engineers came up with the idea of shaping the beacons like the wooden wedges that firefighters carry to keep doors from closing so that hoses they can move unhindered (Dyrks et al., 2009). The new enhanced wedge, however, is not only to be mounted under doors. It was found necessary to add magnets and a hanger to fix the beacon in other places, too, making possible all kinds of MASH-UP mountings with the environment (Figure 12). The new artifact becomes a HANDY MULTI TOOL.

Following the concept of MULTIMODAL ACTS, we added a variety of means to support firefighters in relocating the beacons. Ultra bright LEDs indicate the current status by different colors. A sound emitter at the beacon can be remotely controlled by the firefighter. Radio technology with the antenna integrated at the front of the firefighter's helmet allows the firefighter to literally look for the beacons by moving his head, because we translated the signal strength into a LED bar mounted in the breathing mask (Figure 13, left). In tests with prototypes, firefighters appeared to quickly adopt the integer scales of the LED bar as a SHARED ESTIMATE which could be used to exchange information on approximate distances. In combination with the physically graspable shape, the beacons not only become an artifact that is designed for MULTIMODAL ACTS, but they also degrade gracefully

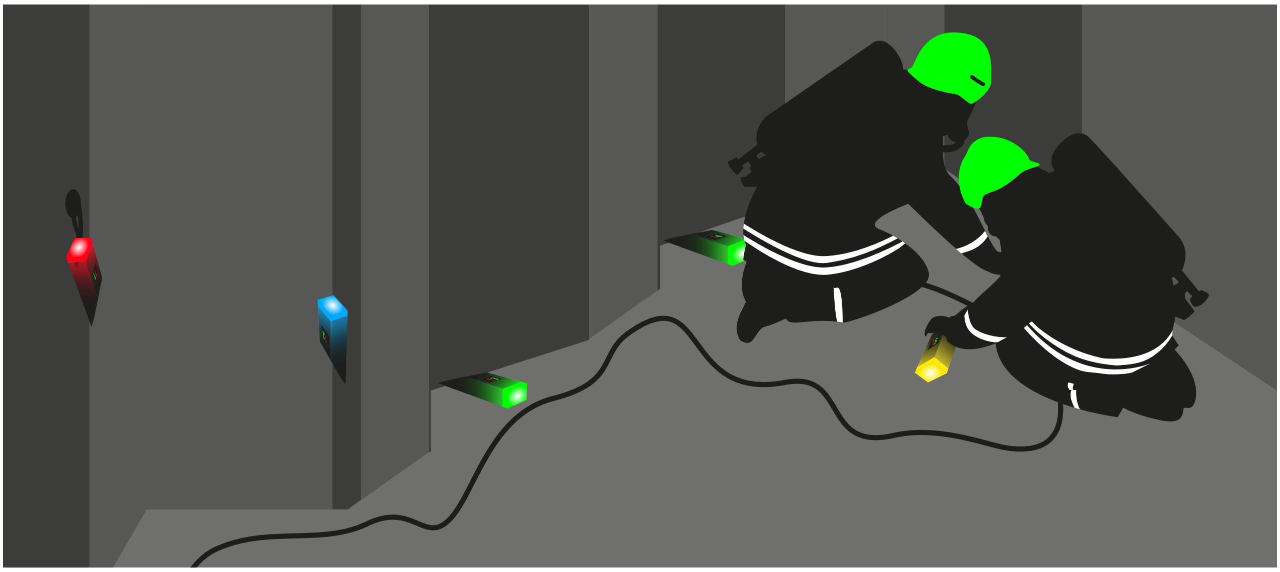

Figure 11. Firefighters place beacons in the building, marking special locations (red), waypoints (blue) fully scanned (green) and partially scanned rooms (yellow).

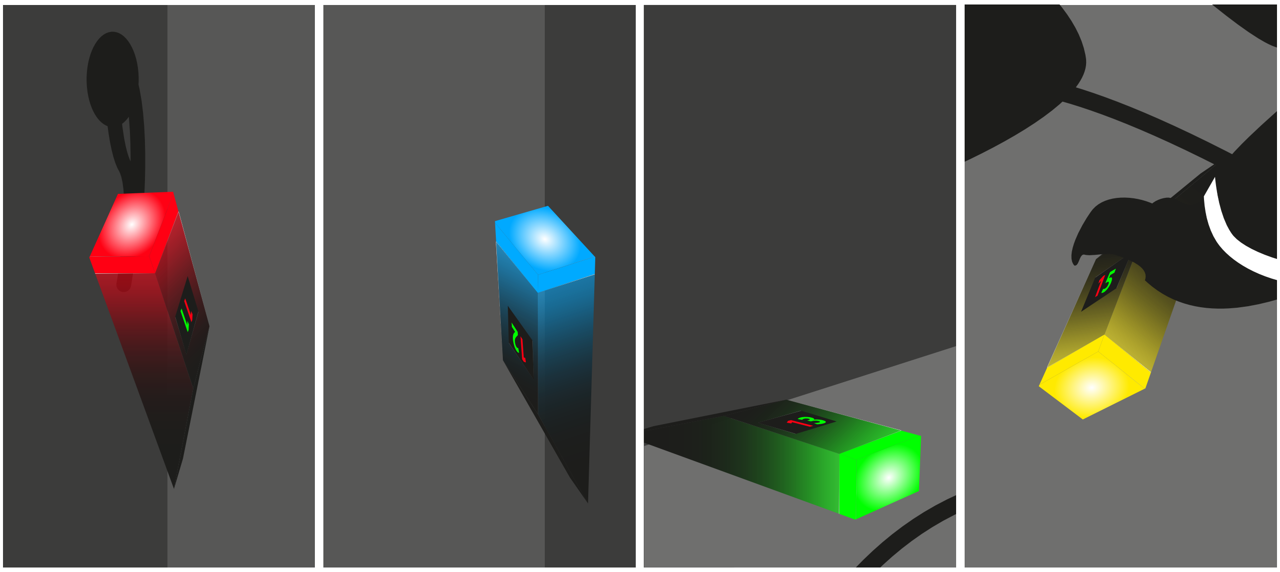

Figure 12. Beacons are mounted in different ways (hanger, magnets, wedge) and manually placed.

in case a certain interaction modality fails and consequently precipitates the pattern TAKE GOOD CARE.

Following the understanding that a novel system also requires new PROCEDURES, firefighters and researchers in participatory design workshops jointly defined the locations where firefighters usually would place the beacons. Also, firefighters introduced four types of status information that they would like to store on a beacon (Figure 11). Additional discussions also defined that within INDEPENDENT UNITS the last person in the team would usually be the one to deploy the beacons (Figure 11). One aspect continuously discussed was the necessity to design a system that might be especially helpful in large structures, and to do so in a way that it is beneficial in all interventions, so that firefighter can train for its use in real-world EXERCISES.

While developed for a specific procedure, firefighters can easily adopt the overall system for other purposes, as suggested by HANDY MULTI TOOLS. The color system indicating statuses is an open tool to be used for other purposes, too. The different mechanisms for relocating beacons also make them open for other uses: they could become a means to measure distances, an alternative light source, or a means of communication through remotely triggered audio signals using a handheld prototype (Figure 13, center) that is envisioned to become arm-mounted.

This new navigation system, while still in prototypical stage, has been tested in simulated interventions at the Fire Service Institute. The results and the design process so far have been very promising. The firefighters are excited about the system, which they enthusiastically describe and promote as a tool with clear potential to provide valuable support in their work (Figure 13, right).

Figure 13. Navigation system in-mask display (left), beacon and handheld device (center), and firefighter explaining the system to stakeholders (right).

Discussion

Reflecting on the previous work which has taken place in identifying and connecting patterns in human practice with the design of interactive artifacts, we identify a number of links in our case between ethnography and the design of ubiquitous computing artifacts using this approach.

First, as indicated by Erickson (2000a, p. 366), a pattern language serves as a rationale in design processes for reflecting on practice changes. This is especially true when the links between patterns make it possible to identify related aspects of practice, and consequent patterns that are likely to be changed through the impact of design. The pattern language serves as a tool to shape future visions and to analyze changes that have taken place.

In our case, the pattern language becomes a means to reflect the design process and the evolution of the concept to support navigation in frontline firefighting. While the initial system was based on THE WAY BACK and outside MONITORING, it also decreased the autonomy of INDEPENDENT UNITS. The beacon-based system, however, provided an alternative and directly supported INDEPENDENT UNITS. While neither option is per se good or bad, the pattern language makes it possible to discuss the impact of these systems on the existing practice. The patterns provide words to talk about the relation of artifacts and practice, as we have done previously. Breakdown situations that occurred in our workshops, for instance when using the initial prototype, could be analyzed in the framework of the pattern language. While our context, 'frontline firefighting', is relatively rigid as manifested in EXERCISE and PROCEDURES, other contexts might allow for more radical changes that a pattern language could help to make visible and thus discussable.

Second, as indicated by Crabtree et al. (2002, p. 269), a pattern language provides a description of a practice, as a resource for solving design problems and as a means to access aspects of the practice that have not yet been supported by design.

In our case, the discovery of frontline navigation practice in MASH-UP and MULTIMODAL ACTS let us revive the overall design concept in such a way that the novel technology could be combined with the environment and could be used in a variety ways, as suggest by the patterns. These practices had not been considered in the initial design. Interestingly, these patterns, once described, were not complex to understand nor difficult to identify in the ethnographic data. They were, nevertheless, easy to overlook when thinking about technical solutions for practice problems, as they are not explicit in the regulations or training materials. The pattern MASH-UP allowed us to rethink the concept of providing location support. The pattern MULTIMODAL ACTS greatly supported the design when looking for integrating means into the beacon that could help the firefighters to locate a beacon. Here, solutions for problems already present in the practice directly inspired the design.

Third, beyond the aspects pointed out by previous research, a pattern language emphasizes that an existing social configuration gains overall stability from a number of patterns. During the design, maintaining balance, at a new stage of evolution, becomes a central concern.

In our case, with the initial system, we picked some aspect of the practice to support the firefighters. MONITORING and THE WAY BACK drove the initial design. We did not foresee the impact that our system might have on other aspects of the overall practice. Frontline firefighting is only successful when it achieves a balance between hierarchy and flexibility, such as described in the patterns INDEPENDENT UNITS and RIGID STRUCTURE and when it achieves a balance between trained plans and situated actions, such as described in the patterns PROCEDURES and MASH-UP. Firefighters combine a set of stiff aspects with a number of concepts that support quick reaction to unforeseen events. This balance, which we summarize as FLUID ORDER, explains how firefighters successfully handle the complexity and dynamics of the situation on the frontline. Supporting this balance by having both procedural and open aspects present in the design is therefore key when designing interactive systems for frontline firefighters.

Fourth, a pattern language shifts the focus in dealing with aspects of human practice. Instead of primarily focusing on the shortcomings that need to be resolved or a specific task that needs to be supported by new technology, the pattern language approach highlights the existence of a larger social configuration, in which the new technology will reside.

In our case, the initial focus on the problems that firefighters have in finding THE WAY BACK, remained a motivation, but was not the key driver for the later design. Instead, existing practices become a resource to learn from and to amplify. Instead of focusing on the problem of isolated INDEPENDENT UNITS, we were able to identify their importance in the overall configuration. The new design closely relates to successful navigation practices that have been developed. This approach also allows for a closer cooperation with the users. Instead of spotting the weaknesses in firefighter practice and trying to fill the identified gaps from the outside, the mutual goal in the pattern language approach is to learn from the existing practice, to understand its inner working and, on this foundation, to jointly evolve the existing practice.

Fifth, and in summary, Alexander's concept of using pattern languages to support design shows itself to be a handy framework for integrating ethnography and design. The pattern language approach contributes to the ongoing goal of bridging the gap between contextual analysis and design (Judge, Neustaedter, Tang, & Harrison, 2010)—a goal that has been discussed for many years (Hughes, Randall, & Shapiro, 1992). While the pattern language approach does not provide a direct path from ethnography to a specific design, it does provide a framework to summarize findings from a variety of ethnographic and design-oriented approaches. The pattern language then supports discussions about the implications for design (Dourish, 2006). Additionally, the approach makes it possible to produce a body of shareable knowledge while, at the same time, addressing situated, contextual needs, aspects that in this combination have previously been considered to be contradictory (Chi et al., 2011). Pattern language describes a working configuration of human practice, which thereby allows us to zoom out to a wider perspective on human-computer interaction (Suchman, 2007, pp. 283-284) and is thus especially relevant when designing ubiquitous computing systems, because it answers the call for integrating the overall social configuration into design processes.

Conclusion & Future Work

In this paper, we have presented our approach of using pattern languages for the design of ubiquitous computing. Ubiquitous computing, in its close intertwinement with human practice, requires the understanding of existing social configurations as the larger context in which design impacts. Alexander's concept of pattern languages has been proposed as a framework for tackling that problem by fusing ethnography and design. With this paper, we solidify the methodology for creating pattern languages by linking the pattern language approach to grounded theory and action research. In our case we presented an example in which we designed a navigation support system. The evolution of the navigation support system was guided by the contextual analysis of the practice that we detail in the pattern language.

Alexander's pattern language provides a framework for linking ethnography and design. In our case it allowed us to distil findings from a number of approaches, such as ethnographic observations, empathic exercises, the introduction of triggering artifacts and participatory design activities. Pattern language can become a rational and communicative means in the design processes. It can serve as a means to make visible unsupported practices and, with its focus on an overall balance and a shift from solving specific problems to evolving an overall configuration, it can provide a wide angle lens that acknowledges that the created technology will reside in a larger and more social context than we might originally think.

While our case is special, given that frontline firefighting practice has been optimized over long periods of time and that its safety-critical nature directly calls for sensible transformations, the benefits of pattern language do not appear to be limited to such cases. Making practices available for design, reflecting on the impact of design, achieving balance in a social configuration or amplifying existing practice are benefits of the approach that are generally relevant for the design of ubiquitous computing. More examples in other settings could provide further insights into the applicability and benefits of the approach, its ability to be applied in projects with a more limited timescale and also its potential for generalizing patterns across domains.

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Endnotes

[1] A more comprehensive overview of research on computing for the frontline can be found in (Denef, Keyson, & Oppermann, 2011).

[2] Detailed descriptions of the patterns RIGID STRUCTURE, INDEPENDENT UNITS and MONITORING can be found in (Denef et al.,

2011). Detailed descriptions for all patterns will be published as part of a PhD thesis (Denef, 2011).

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