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A Pattern Language of Firefighting Frontline Practice to Inform the Design of Ubiquitous Computing

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FIT

A Pattern Language of Firefighting Frontline Practice to Inform the Design of Ubiquitous Computing

Proefschrift

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Abstract

Designing computing systems for frontline firefighting is an open challenge. As of today, little computing support exists for such hazardous environments and designers struggle to build appropriate systems that fit the complex configuration on the frontline.

Following Christopher Alexander's understanding, design is about producing living transformations of existing configurations, it requires a thorough understanding of the situation on-site. Alexander introduces pattern languages as a means to describe existing configurations and to make them accessible for design, to link ethnography and design. This thesis therefore develops a pattern language of firefighters' activities at the frontline to transform the existing practice into a design space for computing support.

Grounded theory, as a qualitative method to identify patterns in empirical data, and action research, as a framework that allows studying the interaction between new technologies and existing practice, solidify the methodology of pattern research and are applied to conduct and analyze workshops with French and German firefighters at professional training facilities. Workshops comprise the observation of existing practice, the active participation in firefighting exercises and the introduction of novel artifacts.

Linked up as a pattern language, 16 patterns describe the configuration of frontline firefighting. The patterns detail how firefighters organize the division of roles and tasks, how they deal with information in a dynamic environment, how they form a social binding, improvise, provide safety and prepare their work.

While similar individual patterns have been described for firefighting and other high reliability professions, the pattern language, beyond these aspects, provides an integrated perspective on the frontline work; it allows developers to reflect technological concepts and supports the participatory design process of ubiquitous computing systems.

Dutch Abstract: Het ontwerpen van computer systemen om de brandweer te helpen bij de brandbestrijding is een enorme uitdaging. Op dit moment zijn er nog nauwelijks ondersteunende computersystemen om effectief te helpen in de gevaarlijke situaties waarin de brandweer regelmatig terecht komt. Onderzoekers vinden het uitermate lastig om goede ondersteunende computersystemen te ontwerpen die passen bij de complexe omgeving waarin de brandweer zich vaak bevindt. Volgens Christopher Alexander is ontwerpen in essentie het creëren van leefbare veranderingen van bestaande configuraties. Een goed ontwerp vereist daarom een gedegen inzicht in de praktijk. Alexander introduceert patronentalen als een middel om inzicht te verkrijgen in bestaande configuraties zodat het mogelijk wordt om deze configuraties te ontwerpen door verbindingen te leggen tussen etnografie en ontwerp.

Dit proefschrift ontwikkelt daarom een patronentaal voor de activiteiten van brandweermensen bij brand om zo de bestaande praktijk te vertalen naar een ontwerpruimte voor computerondersteuning. "Grounded theory" is gebruikt om patronen in de empirische gegevens te vinden en "Action research" is gebruikt als raamwerk om de interactie tussen technologie en bestaande praktijk te bestuderen. In professionele opleidingscentra zijn beide methoden toegepast om het gedrag van Duitse en Franse brandweermannen in bepaalde werksessies te analyseren. In deze werksessies werd de bestaande praktijk van brandweeroefeningen geanalyseerd en werd de impact van de introductie van nieuwe voorwerpen bestudeerd.

Uit onze conclusies blijkt dat 16 verschillende patronentalen gezamenlijk de configuratie van actieve brandbestrijding beschrijven. Deze patronen laten in detail zien hoe brandweermensen zich organiseren en rollen en taken verdelen, hoe zij omgaan met informatie in een dynamische omgeving, hoe zij sociale relaties vormen en hoe zij improviseren, veiligheid verzorgen en hun werk voorbereiden.

Hoewel eerdere studies vergelijkbare individuele patronen hebben beschreven voor het bestrijden van brand en andere beroepen waar een hoge betrouwbaarheid vereist is, is deze patronentaal uniek omdat het een integraal perspectief biedt op het werken in de vuurlinie. Het biedt ontwerpers de mogelijkheid om technologische concepten te testen en ondersteund participatie in het ontwerpproces van alomtegenwoordige computersystemen.

Acknowledgements

I would like to thank all my colleagues at Fraunhofer FIT, especially Leonardo Ramirez, Tobias Dyrks, Tobias Schwartz and the library team, and my supervisors David V. Keyson and Reinhard Oppermann for the mutual work throughout the years, thoughtful discussions and inspiring guidance.

I would also like to thank the committee members as well as Renate Wresch-Bruker and Christoph Biela for providing feedback and comments on earlier drafts of this thesis and Melody Barlage and Arjan van den Born for help with the Dutch translations.

This work would not have been possible with the invaluable support of the Fire Service Institute in Münster, Germany, the firefighters of Cologne, Germany, and Paris, France who allowed me to get a first-hand experience of the work on the frontline and the support of all the project partners in the landmarke and WearIT@Work projects.

The research has been partly funded by the German government in the context of the civil security research framework and the landmarke project (contract no. 13N9916), the European Commission in the context of the WearIT@Work project (contract no. 004216), the Fraunhofer Society and the Fraunhofer Institute for Applied Information Technology (FIT) in the context of the open design project.

Related Publications

The research described in this work has partly been previously published, presented and discussed with scientist in the fields of Human-Computer Interaction, Design and Safety-Critical Information Technology. The following list provides an overview of the articles published and describes their contents and their relation to this work.

Full Papers

- Denef, S., and Keyson, D.V., Talking about Implications for Design in a Pattern Language, SIGCHI Conference on Human Factors in Computing Systems. CHI'12, 2012, ACM, under revision.

  This paper presents the results from the introduction of the pattern language to developers as a means to reflect on its implications for design.

- Denef, S., Oppermann, R. and Keyson, D.V., Designing for Social Configurations: Pattern Languages to Inform the Design of Ubiquitous Computing, in International Journal of Design, accepted pending minor revisions.

  This paper presents the methodology and overall pattern-based approach of this thesis. It also presents a summary of the resulting pattern language and its link to the design case.

- Denef, S., Keyson, D.V., and Oppermann, R., Rigid Structures, Independent Units, Monitoring: Organizing Patterns in Frontline Firefighting, in Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. CHI'11, 2011, ACM: Vancouver, Canada. 1949–1958.

  This paper presents RIGID STRUCTURE, INDEPENDENT UNITS and MONITORING as interacting patterns of the overall configuration of firefighting frontline practice and discusses their relation to the design of ubiquitous computing artifacts.

- Denef, S., Ramirez, L., Dyrks, T., and Stevens, G., Handy Navigation in Ever-Changing Spaces: An Ethnographic Study of Firefighting Practices, in Proceedings of the 7th ACM Conference on Designing Interactive Systems. DIS'08, 2008, ACM: Cape Town, South Africa. p. 184–192.

This paper brings together the results from the ethnographic investigation and the introduction of the Digital Command Post system at the Parisian Firefighters. With its focus on frontline navigation practices, it presents aspects of the work that in this thesis become part of the patterns INDEPENDENT UNITS, MULTIMODAL ACTS, and MASH-UP.

- Dyrks, T., Ramirez, L., and Denef, S., Designing for Firefighters–Building Empathy through Live Action Role-Playing, in Abstracts of the International Conference on Information Systems for Crisis Response and Management, ISCRAM'09. 2009: Gothenburg, Sweden, May 10–13, 2009.

  This paper presents the role-playing workshops with the firefighters and the empathic approach that is part of this work's methodological concept.

Short Papers

- Denef, S., Ramirez, L., and Dyrks, T., Letting Tools Talk: Interactive Technology for Firefighting, in Extended Abstracts of the SIGCHI conference on Human Factors in Computing Systems, CHI'09. 2009, ACM: Boston, MA, USA. p. 444–447.

  This work-in-progress report presents results from the study on the tools of firefighters described in the HANDY MULTI TOOLS pattern.

- Ramirez, L., Denef, S., and Dyrks, T., Towards Human-Centered Support for Indoor Navigation, in Proceeding of the Twenty-Seventh Annual SIGCHI Conference on Human Factors in Computing Systems CHI'09. 2009, ACM: Boston, USA. p. 1279–1282.

  The relation between the navigation support system presented in this note and the pattern language is part of the discussion of this thesis. Additionally, the design of the system drives the design-oriented research activities.

Workshop Contributions

- Denef, S., A Pattern Language of Firefighting Frontline Practice to Inform the Design of Ubiquitous Computing. Doctoral Consortium Intl. Conference on Ambient Intelligence. AMI'11. 2011. Springer. forthcoming

  This note presents the research questions and approach of this thesis.

- Denef, S., Ramirez, L., and Dyrks, T., A Deep Dive into the World of Firefighters, Presented at the Bridging the Gap Workshop of the SIGCHI Conference on Human Factors in Computing Systems (Atlanta, GA, USA, April 10–15, 2010). CHI'10. 2010.

  This position paper proposes the use of ethnographic, empathic and design-oriented research as a means to prepare the jump between user research and design activities as proposed in the discussion.

- Denef, S., Human-Computer Interaction Techniques in Firefighting, Doctoral Consortium. in Human-Computer Interaction–INTERACT'09. 2009, Springer. p. 864–867.

  This position paper argues for an ethnographic research approach in designing human-computer interaction techniques for firefighters.

- Dyrks, T., Denef, S., and Ramirez, L. An Empirical Study of Firefighting Sensemaking Practices to Inform the Design of Ubicomp Technology. Presented at the Sensemaking Workshop of the SIGCHI Conference on Human Factors in Computing Systems (Florence, Italy, April 5–10, 2008) CHI'08. 2008.

  This position paper presents sensemaking practices of frontline firefighting work some of which are covered by the EVER-CHANGING PUZZLE and MASH-UP patterns.

Other Publications

- Denef, S., The Second Step: Learning from Firefighters about Good Management. Global Peter Drucker Forum 2011, Vienna, Austria. forthcoming (4. Prize, Essay Competition "Management what is it good for?")

  This essay puts the firefighting practice described in the pattern language into the context of Peter Drucker's research on management and explains what managers of other professions can learn from firefighters about management.

- Scholz, M., Scholl, P., Busse, M., Stoetzer, M., Budde, M., Shishkova, D., Riedel, T., Beigl, M., Ramirez, L., Denef, S., Betz, M., and Dyrks, T., Video Submission: A MVC Prototype for the landmarke Firefighter Navigation System, in Internet of Things Conference 2010: Tokyo, Japan.

  This video presents the design of the navigation support system and sets it in context to frontline firefighting practice.

Foreword by the Institute Director

At the Fraunhofer Institute for Applied Information Technology FIT we investigate human-centered computing to optimize the usefulness of information and cooperation systems in their interplay with human work practice and organizational processes.

The emergency management domain is a typical example. It is presently characterized by its complex requirements and–to a large extent–the absence of IT support on the frontline. As one key example, Fraunhofer FIT has taken up the challenge to support first responders in firefighting. The European project WearIT@Work has performed research on wearable computing systems for this domain, and developed both planning methodologies and initial artefacts for navigation. The BMBF project 'landmarke' has expanded the design towards a navigation support system for frontline firefighters which also forms the technical kernel of the thesis by Sebastian Denef. The European project SOCIONICAL investigates larger-scale firefighting settings, and BRIDGE aims to support large-scale crises across national and organizational boundaries.

Based on experiences in these projects, several doctoral theses at Fraunhofer FIT have been investigating firefighter work practices with different methodologies, and developing methodologies and specific solution proposals for advanced technologies.

The thesis by Sebastian Denef makes two contributions. Firstly, by case studies from his participation in three of the mentioned projects, it contributes towards an improved empirical foundation for understanding firefighting practice. Secondly, it takes a novel approach for human-centered design processes, connecting ethnographic research with the design of IT systems. With the emergence of ubiquitous computing systems, traditional approaches of capturing and modeling work processes often ignore a larger social dimension that gains an increasing importance when computing becomes embedded into objects of everyday life. Understanding human practice and its relevance for the design of IT systems is an open research question that requires an interdisciplinary answer from social and engineering sciences. Here, the development and use of pattern languages, as proposed by Sebastian Denef, builds a promising bridge between ethnographic user studies, and the design of IT systems, here specifically novel navigation systems for firefighters.

The reader thus gains an in-depth perspective of the fascinating work of frontline firefighters and the challenge of designing of IT systems that support their work; she also learns of an approach that connects our understanding of human practice with the task of IT design and is therefore relevant for the general challenge of human-centered design of computing systems.

Aachen and Sankt Augustin, October 2011
Matthias Jarke, Fraunhofer FIT

Die Institute des Fraunhofer-Verbunds Informations- und Kommunikationstechnik (IuK) entwickeln gemeinsame Strategien für die anwendungsorientierte Forschung.

In der Reihe „Fraunhofer Series in Information and Communication Technology“ publizieren die IuK-Institute Dissertationen, Habilitationen sowie herausragende Diplomarbeiten, wissenschaftliche Monographien und Forschungsberichte. Diese Publikationen dienen der Fundierung der anwendungsnahen Fraunhofer-spezifischen Forschung und Vorlaufforschung.

A Note to the Reader

To support the reader, I added abstracts at the beginning of each chapter and marked sentences bold that summarize the following paragraphs. Should you want to read this work within less than an hour, you may choose to flip through the pages and only read these abstracts and the sentences in bold.

This approach of writing is inspired by Christopher Alexander (1979) who argued that for the designer an overall understanding is more valuable than the knowledge of scattered details.

Contents

Preface

Why not start with a tragic accident?

Research about computing systems for frontline firefighters can easily be motivated by a tragic accident. Trapped in a hazardous environment a firefighter, whose life may be at risk while trying to save other peoples' lives, could greatly benefit from systems that support him in finding his way out or calling for help.

First, a motivation by a tragic accident would only provide a distorted image of reality and picture firefighting as a faulty practice, which it is not.

Indeed, these accidents happen and indeed, the potential of computing for the frontline has not been unleashed. Yet, the 19 U.S. firefighters who died in accidents in building fires in 2009 (FEMA 2010: 11) have to be put in the context of an approximate of 480,500 fires in building structures that U.S. firefighters fought in that year overall (Karter 2010: i). These burning buildings included some highly dangerous settings, they caused the death of 2,565 civilians and injured almost six times as many (Karter 2010: i). Despite hazardous conditions firefighters operated safely in these workplaces, at least most of the time.

Making firefighting more safe and effective, remains, nevertheless, an open challenge. Even though almost no computing systems exist today on the frontline, the quest for real-time, networked information drives firefighters and computer engineers alike and current computer science research projects push the development of computing systems for safety-critical domains.

Second, for firefighters and in general, computing systems do not only have the potential to solve specific problems or prevent tragic accidents that might originally drive designers' efforts. Computing systems furthermore are situated in existing configurations, they interact with our patterns of doing, thinking and feeling.

When designers understand firefighting as a largely successful practice, they have to acknowledge that a systems that they are about to build may not solely do good to firefighters' work. In order to design systems for frontline firefighters that provide meaningful support, designers will need to understand thoroughly the interaction of these systems with existing firefighting practice; a practice that has been developed since ancient Rome and Caesar Augustus (Kenlon 2008).

So let's start differently. The following is my attempt to tackle the very general challenge of designing computing systems that become closely interwoven with human practice for the very specific case of frontline firefighting.

My research explores the domain of frontline firefighting, its overall configuration and interaction with novel computing systems. This work is intended as a means to support technology designers in reflecting and discussing with practitioners the changes for the practice that new computing systems produce.

Bonn, October 2011
Sebastian Denef

1 Introduction

Supporting frontline firefighting with computing systems is an open challenge. Designing ubiquitous computing systems, which are meaningful to practitioners, requires a thorough understanding of the situation on-site. The goal of this work is to reveal the configuration of frontline firefighting practice as a means to inspire and guide the design of computing support.

1.1 Computing to Support Frontline Firefighting

Frontline firefighting is a complex task in a hazardous environment.

The work on the frontline of an intervention is complex and requires a set of very specific skills and tools. It is often conducted in buildings full of smoke, which can only be accessed by crawling on the floor due to the heat distribution. In these environments, firefighters can only perform their work using fire protective clothing and breathing apparatuses. Such extreme work conditions make the work of firefighters unique, a “magic work”, as Kaprow (1991) put it, that is internationally valued as the most trusted profession (Hofmans and Eisenblätter 2010).

Ubiquitous computing solutions could provide viable support to firefighters working on the frontline.

Ubiquitous computing, as introduced by Weiser (1991), provides researchers with an alternative vision of the future of computing. Building on ideas from postmodernism and phenomenology, Weiser pictures a world in which the human being encounters the world mediated by a large number of context-aware computers (Figure 1). Embedded into the environment, they work so seamlessly that the user is not aware of them. Computers become invisible to the user, as did electric motors. In contrast to the approach of virtual reality that aims at enriching reality with a new, virtually created world that “fool[s] the user” (Weiser 1993: 76), ubiquitous computing is envisioned to weave computers into “the fabrics of everyday life” (Weiser 1991: 66), to embed them into devices of daily use. In Weiser’s descriptions “computers in light switches, thermostats, stereos and ovens help to activate the world” and “will be interconnected in a ubiquitous network” (Weiser 1991: 68). In the first phase of ubiquitous computing (Weiser 1992), mobile devices may range from small tag-like devices to large displays that support daily tasks of human life (Weiser 1991).

These always-on computing devices will bring about “nothing fundamentally new” but make “everything faster and easier to do” and “transform what is apparently possible” (Weiser 1991: 75).

Today, ubiquitous computing remains central to the computing visions of tomorrow. In 2007, the forum ‘HCI 2020’ brought together 45 senior

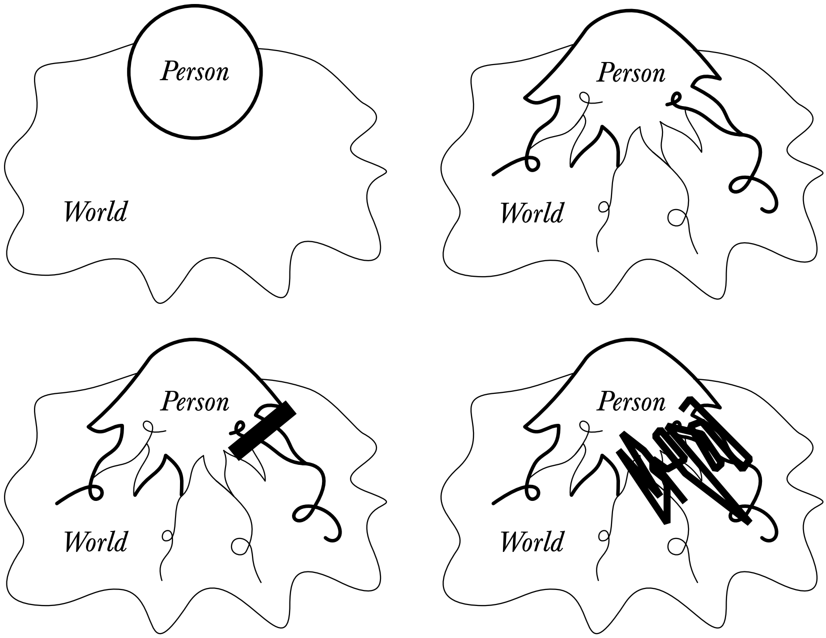

Figure 1: Weiser rejects a perspective that separates the individual from the world (top left) and argues for a postmodernist understanding (top right). While traditional computers aim to form an interface between the person and the world (bottom left) ubiquitous computing is pervasive (bottom right).
(Redrawn from Weiser (1996))

researchers from the fields of computing, design, management science, sociology and psychology to discuss the challenges and future road map for human computer interaction. The "ubiquity era" of computing in 2020 and beyond will be characterized by "thousands of computers per user" (Harper et al. 2008: 15).

Inspired by the seminal vision of Weiser, researchers in the field of safety-critical HCI go beyond home or office environments and aim at providing emergency responders working in life-threatening situations with new means to cope with their difficult tasks. Current IT research targeting the firefighting domain proposes systems to support navigation, health monitoring or communication. A number of projects share the goal of supporting firefighters working on frontline with ubiquitous computing solutions

(FeuerWhere 2008, landmarke 2008, Tri-Sentinel 2008, U2010 2008, WearIT@Work 2008).

The topic of computing support for public safety in general and firefighting specifically, is part of the political agenda. This January, U.S. President Barack Obama, in his remarks about the state of the union, explained the importance of enhancing the U.S. communication network infrastructure, among others, by the need of providing computing support to firefighters.

> Within the next five years, we'll make it possible for businesses to deploy the next generation of high-speed wireless coverage to 98 percent of all Americans. This isn't just about – (applause) – this isn't about faster Internet or fewer dropped calls. It's about connecting every part of America to the digital age. […] It's about a firefighter who can download the design of a burning building onto a handheld device. (Obama 2011)

By explicitly naming the firefighting domain, the European Commission funds research projects under their call "First responder of the future" (European Commission 2009: 23). Projects should enhance the operational effectiveness and capability and reduce injury or loss of life of first responders by optimizing their protection equipment using sensors and means of communication or by guiding first responders in the field.

As of today, little computing support exists for such hazardous environments. Firefighting frontline practice and its relation to ubiquitous computing are yet to be discovered.

The work context on the frontline of an intervention poses a complex set of requirements for the design of computing systems.

Some researchers avoid the constraints of the frontline by focusing on the part of the firefighting that takes place in relatively safe and less restrictive environments and develop, for instance, systems to support commanders (e.g. (Landgren and Nulden 2007)).

Research projects targeting the frontline often use firefighting scenarios only as a motivation or explanation for the need of a certain technological development (e.g. (Jiang et al. 2004a, Wilson et al. 2007)). The approach of these projects is to simply adopt mobile computing systems designed for everyday use (Jiang et al. 2004a) or to rely on technological advances such as head-mounted displays (Wilson et al. 2007), without evaluating the fit of these systems with real-world conditions.

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 and Roast 2008)). Firefighting practice is, however, very likely to be negatively affected by systems that do not take into account the full complexity of the task and the challenges posed by the work environment.

Despite promising visions and ongoing research efforts, firefighting on the frontline of an intervention, has been an activity with almost no computing support, to this day.

1.2 Social Dimensions of Ubiquitous Computing

Ubiquitous computing faces the complexity of life, in contrast to Weiser's vision of seamlessly integrated devices.

16 years after Weiser's original publication, Bell and Dourish (2007) acknowledge that the ubiquitous computing vision has indeed served as a research endeavor and set the technological agenda. Today, ubiquitous computing has come, at least partly, to the world. Wireless internet access and mobile devices, computers to make driving cars more safe and the use of energy in the home more efficient, are examples for this development. 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 and Dourish 2007: 133). Dourish, who himself contributed to Weiser's work, and Bell argue that instead of waiting for the perfect vision of Weiser to arrive, researchers should address these current issues. Existing problems in the process of integrating ubiquitous computing are not a matter of an incomplete vision or a matter of time, rather, they are a direct result of the complexity intrinsic to the interaction of humans with ubiquitous computing technologies, they are linked to the nature of a social world and need to be met.

The close interweavement of computers with human life raises new issues to be addressed. Rather then looking for optimizing performance or the efficiency in completing tasks, there is the need to understand users in their respective contexts and to deal with social issues such as meaning and value.

As Dourish (2001: 28-53) argues, the difference of human-computer interaction in ubiquitous computing requires a new theoretical foundation, as ubiquitous computing increases the physical and social dimension of the interaction. While for desktop computing the means of interaction are defined, ubiquitous computing allows for new forms of interaction. Embedded in other objects, computers become tangible. Embedded, networked computers that are closely interwoven with human life and social encounters require integrating the social dimension in the system. The physical and social dimensions of computing make Dourish build on the philosophical movement of phenomenology. He brings to the research on human-computer interaction the concept of embodiment. Under this perspective, the human actor is engaged in a continuous physical and social interaction with the world, she lives embodied. As Dourish puts it, embodiment "is the property of our engagement with the world that allows us to make it meaningful", embodied human-computer interaction is "the creation, manipulation, and sharing of meaning through engaged interaction with artifacts" (Dourish 2001: 126). Rather then looking for optimizing performance or the efficiency in completing tasks, embodied interaction looks for meaning. Appropriation of computing technology is a central concern, as "users, not designers, create and communicate meaning" (Dourish 2001: 170).

Harrison et al. (2007) diagnose that this shift of focus in human-computer interaction research (HCI) constitutes a shift in the research paradigm of HCI. According to Kuhn (1970: 10) a research paradigm defines "the legitimate problems and methods of a research field" it "stands for the entire constellation of beliefs, values, techniques […] shared by the members of a given community" (1970: 175). From the perspective of the 'situated perspective' paradigm proposed by Harrison et al., the focus of HCI research is no longer on optimizing the information flow between the user and computer, the user's behavior is no longer modeled as a cognitive machine, instead, the user is understood as being phenomenologically situated:

Meaning is interpreted as a construction by the user. Users are seen in their respective contexts. Computing, too, is understood situated. Consequently, researchers have to draw their knowledge from a wide range of disciplines, considering the manifold situated aspects. The paradigm also brings about a new relation to theory. While traditionally theory development or validation is the primary reason for conducting research, with the new paradigm the focus shifts towards design and theory becomes a means to support the design process.

For Harper et al. "the bottom line is that computer technologies are not neutral–they are laden with human, cultural and social values" (2008: 57). In the face of ubiquitous computers, human-computer interaction hence extends beyond issues of usability or user experience and needs to develop a new focus concerned with human values. This in mind, the issue also touches the epistemology and methodology of research and design of human-computer interaction, it …

> requires HCI to shift its epistemological constraints away from their psychological roots towards other approaches, such as the philosophical, where conceptual sensitivity to meaning, purpose, and desire is possible. (Harper et al. 2008: 77)

To make room for social concerns within a user-centered design cycle, Harper et al. suggest the introduction of a new phase at the beginning of the cycle that specifically focuses on human values. This phase will include "reflective thought and conceptual analysis drawing on other disciplines, which might include those as diverse as philosophy, psychology, art, literary theory, cultural studies, anthropology, sociology or design" (Harper et al. 2008: 59).

HCI research in the 'situated perspectives' paradigm explicitly focuses on values to understand "what it means for a system to be 'good' in a particular context." (Harrison et al. 2007)

Following these writings, the interaction between human and computers takes place in a larger and already existing context, it is a personal and situated activity that attributes meaning to the technology.

1.3 Frontline Firefighting as a Configuration

As a consequence of the social dimension of ubiquitous computing, designers of technology need to consider firefighting frontline practice as a social configuration.

In order to design technology that fits the frontline, firefighting frontline practice needs to be understood as a lived practice, a situated action that is influenced and guided by a number of aspects and will interact with ubiquitous computing tools. The context of use is a configuration of agencies, as Suchman (2007) described it. Commenting on the research on intelligent computing systems, she calls for a perspective that takes a broader range of aspects into account.

> [T]his spatial attenuation of the relevant field of agencies is accompanied by the staging of performances repeatable over time through accounts and demonstrations that have themselves been congealed into modes of immutable mobility. Our task as analysts is then to expand the frame, to metaphorically zoom out to a wider view that at once acknowledges the magic of the effects created while explicating the hidden labors and unruly contingencies that exceed its bounds. (Suchman 2007: 283-284)

Instead of picking out only certain aspects or requirements relevant to a particular envisioned technology, instead of creating artificial scenarios in which technology is supposedly useful, there is the need to build a wider perspective understanding of the lived practice and the effects and changes that novel artifacts have on the practice (Figure 2).

Understanding the inner workings of frontline firefighting to design systems that fit the existing practice is a special challenge, as the context on the frontline is very different from everyday experiences of technology designers.

While introducing technology into the life-threatening work on the frontline shows not to be an easy task, firefighters themselves are experts on how to deal with the challenging environment. Current practices are rooted in long time experiences, with firefighting as a profession dating back to ancient Rome and Caesar Augustus (Kenlon 2008). Clearly, leveraging this experience when designing tools has the potential to be highly beneficial.

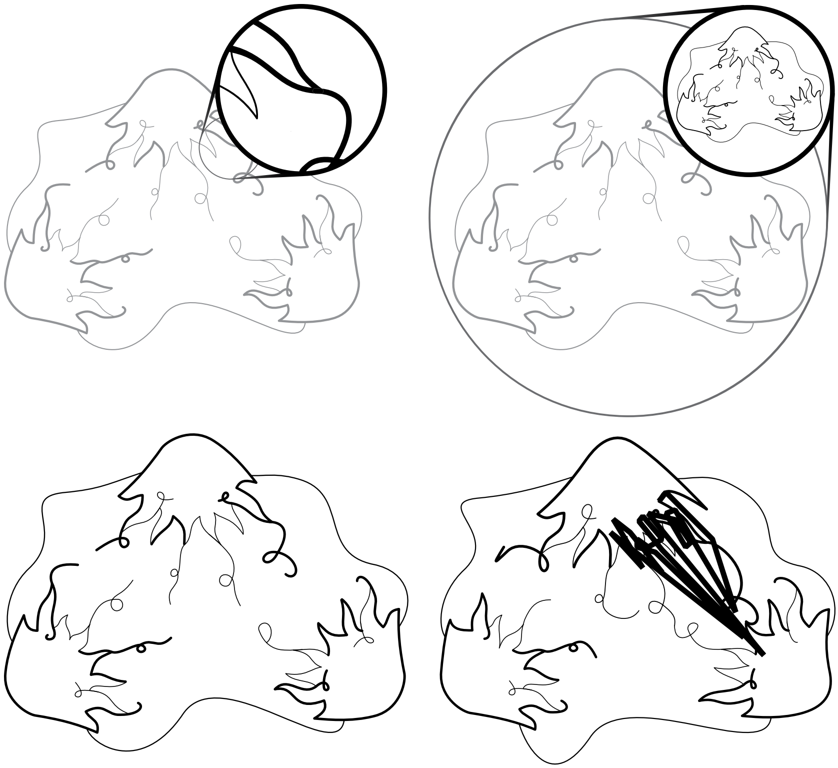

Figure 2: Suchman (2007) argues that technology design requires to metaphorically zoom out from small details (top left) to a wider few (top right). Also, she argues that the overall existing configuration (bottom left) is changed by new artifacts (bottom right).

It is, however, crucial to grasp and communicate experience embedded in work practice and to understand the relation and relevance for the design of ubiquitous computing technology.

On the one hand firefighters know how to successfully accomplish their missions using existing tools but they may not be able to explicate the inner workings of their work and also lack experience with novel systems and the knowledge how to design them. On the other hand, technology designers are confronted with the challenge to provide meaningful tools for a work context fairly different from their daily experiences. This gap leaves the design space, for ubiquitous computing support on the frontline of an intervention yet to be discovered.

With this work, I therefore build an empirical foundation that reveals the configuration of firefighting frontline practice as a means to guide and inspire the design of ubiquitous computing systems.

This research addresses the questions: How do frontline firefighters successfully cope with the hazardous work environment that they are confronted with? How is this existing practice being influenced by ubiquitous computing technologies? What can we learn from the interaction between new technologies and existing practice for the design of future ubiquitous computing systems?

The result of this investigation should support both technology designers and practitioners in jointly designing novel, meaningful solutions. The thesis serves technology designers as an insight into existing practice, a starting point for envisioning systems, an analytical lens when deciding on what to design or when evaluating existing systems. Practitioners, respectively, gain a formalized description of their work practice that they can use to reflect on introducing new technology and to change practice.

The thesis is structured as follows: Chapter 2, 'Related Work', shows the need for research of firefighting frontline practice. It also introduces the approach of Christopher Alexander that design processes are transformations of existing configurations supported by pattern languages and shows how this approach has been applied. Chapter 3, 'Methodology', presents the methodological framework to create pattern languages by linking pattern research to grounded theory and action research. Chapter 4, 'Field Studies', describes the workshops with firefighters conducted at professional training facilities that form the empirical base. In chapter 5, 'A Pattern Language', 16 patterns describe the configuration of frontline firefighting and are linked up as a pattern language. Chapter 6, 'Informing Design', describes, on the one hand, how the emerging understanding of the frontline practice impacted the design of a navigation support system and, on the other hand, how the language allowed developers with no prior knowledge of the practice to reflectively discuss technology proposals that target frontline firefighters. Chapter 7, 'Discussion', compares the pattern language with findings from other high reliability organization and shows how the language provides an integrated perspective on frontline work. Chapter 8, ‘Conclusion’, takes a retrospective look at the research, and shows how the pattern language transforms the existing frontline practice into a design space for ubiquitous computing support and how the approach is relevant for design processes apart from burning buildings, too.

2 Related Work

Currently, frontline firefighting practice has yet to be studied in detail. Technology design for command and control of firefighting operations reveals a tension between hierarchic structures and situated actions. For the frontline, technology designers struggle to handle the complex context in design processes. Following architect Christopher Alexander, design processes are transformations of existing configurations supported by pattern languages. Pattern languages based on ethnographic research have shown to be a useful means to inform design processes and to link ethnography and design.

2.1 Understanding Frontline Firefighting[1]

The work of firefighters on the frontline has been analyzed from the perspective of organizational science providing insight of the social dynamics of small groups in danger, however, does not reveal the current, professional practice of urban firefighters.

Studying frontline firefighting from the perspective of organizational theory, Weick's (1993) central interest is to understand what causes firefighting operations to go wrong and what causes peoples' actions that turn out to be fatal. Weick (1993) provides an analysis of an firefighting incident that happened in 1949. In the 'Mann Gulch' disaster, 15 firefighters were dispatched via airplane as 'smokejumpers' to a forest fire. During the operation, the fire that the firefighters originally considered to be controlled easily, suddenly developed in a life-threatening way not foreseen by the team. Only three firefighters survived the incident. Without access to the field of an accident that happened 44 years before his analysis, Weick bases his work on an award-wining novel by Maclean (1992) that provides an in-depth record of the incident. Maclean tried to reconstruct the event in detail, visited the scene with survivors and provided both a narrative and a documental account of the events.

Weick's study is an example for understanding the complex social structure in safety critical work. He studies the records of the event by applying the analytical perspective of 'sensemaking' that focuses on how people make accountable the reality to themselves. Using this analytical perspective, Weick shows that different factors such as the underestimation of the fire, a lack of understanding for the instruction given, actions taken by the

[1] A note on the structure and contents of this chapter: As I will explain in greater detail in the chapter 'Methodology', this research applies the grounded theory method, following which a theory emerges over the course of the research driven bottom-up by empirical data–instead of applying already existing theories from other contexts. The chapter 'Related Work', therefore, identifies the need for research on frontline firefighting (2.1), describes the challenge of designing for this field (2.2) and for social configurations in general (2.3 & 2.4). The comparison of frontline firefighting with other, related professions is part of the discussion in the section 'High Reliability Organizations' (7.1). The developed pattern language then already serves as a theoretical lens.

foreman and a social disintegration of the group were the major causes for the tragedy. The firefighters who survived, on the contrary, were able to sustain their social integrity and could make positive sense of the situation that they faced. For Weick, sensemaking allows to understand reality as "an ongoing accomplishment that emerges from efforts to create order and make retrospective of what occurs." (Weick 1993: 635) This concept contrasts the perspective of decision making theory that social scientist considered a "modern classic of truth, beauty and justice" (Brunsson and Adler 1989: 2) (quoted from Reed (1991)) that works as an analytical lens to link decisions and actions. Weick refers to Reed's critique who stated that "the linkages between decisions and actions are loosely-coupled and interactive rather than linear" (Reed 1991). Sensemaking, instead, "emphasizes that people try to make things rationally to themselves." (Weick 1993: 635)

Despite the insightful analysis of the Mann Gulch incident by Weick, one should remember that the firefighters studied here were far from being a professional crew. The team mostly comprised college students starting from the age of 17, who in their semester break volunteered to be firefighters as a summer job for money and excitement. They received a three-week training (Maclean 1992: 41), had very limited experience and were not familiar with working together. Instead of professional equipment, they were fighting fire in jeans and t-shirts. After the incident, the commander even could not recall the names of his teammates (Maclean 1992: 108).

While we certainly can learn from this tragic event about the social dynamics in teams faced with stress, it is not to be confused with a study of professional firefighting crews. On the one hand, this crew was condemned to fail when faced with an exceptional situation. The three firefighters who survived not only kept social integrity but also, in the case of the foreman, had a much more professional level of experience or, in the case of the two men who survived, were physically strong enough to run away from the fire (Maclean 1992: 97). On the other hand, firefighting in urban areas cannot only benefit from professional equipment and experience; it is also confronted with different challenges. Usually, it takes place in densely populated areas and firefighters often engage buildings. Therefore, studying modern firefighting practice in urban spaces should provide new insights.

Another perspective on firefighting frontline practice stems from anthropology. While through interviews the character of the job is described, the research does not present details of the frontline practice.

An ethnographic study from the 1970s investigates the nature of professional firefighting and discusses some of the characteristics. Woods (1972) publishes the results of a field study at a U.S. fire station. Based on a number of on-site interviews, Woods reports on the procedures of firefighting operations, as well as on the daily routine of firefighters. She also describes for firefighters the perceived image of and interaction with the general public. Wood describes firefighting as a unique and uniquely dangerous profession, which, in the U.S. of the 1970s, claimed more victims than any other profession. Firefighting is hard to be understood from the outside, "many things that appear simple and inconsequential to the uninitiated are important, significant parts of the firefighter's life" (Woods 1972: 221–222). Firefighters face the challenge to react to novel situations, and there are "no two fires […] ever alike" (Woods 1972: 225), as a firefighter stated. Finding people dead and working only in hazardous situations has an effect on firefighters.

> A certain sense of trauma surrounds a job that depends on the force of flashing light, screaming sirens and speed to reach and rescue the victims of fire and emergency (Woods 1972: 237).

According to the research, firefighting is a physically demanding job at the border of life and death. The uncertainty of the job and the related risks, make firefighting an especially dangerous profession. Woods work provides an interesting few on firefighting culture, she does, however, leave out the details of the work on the frontline.

Some research stemming from decision-making theory presents firefighting and the work of commanders as a highly situated and iterative process.

Coming from the theoretical concepts of how to approach the context on the frontline to existing studies of this special work environment, I shall discuss the works that study firefighting practice. Frontline firefighting is difficult to be studied since the work context of real interventions is almost impossible to access for non-firefighters and there are only limited accounts of the work on the frontline. Nevertheless, there are publications that study firefighting from different perspectives relevant to understand the work on the frontline.

Learning from the actions on frontline, research focusing on decision-making has studied the actions of incident commanders. While not solely focusing on firefighters, Klein (1999) provides several examples of firefighting frontline work in order to analyze the actions of the commanders. Klein argues that firefighters do not make decisions in the classical sense, as conscious, rational, comparative choices of options (Klein 1999: 12). For firefighters, instead, options are tacit and can only be revealed when taking into account the various, often subtle and unconscious details in an intervention. Klein's 'recognition-primed model' for decision-making therefore understands decision making as an iterative process in which the commander compares typical situations to the context on-site.

Outside the social sciences, engineers investigate requirements and design options for firefighting engines and provide an in-depth statistical account of firefighting from the 1970s.

Supported by the German Government for Research and Technology, engineers of Porsche AG conducted an in-depth study to inform the design of fire engines (Beyerle et al. 1978). On 1000 pages the study discusses numerous aspects of German firefighting and also compares the German setting to other countries. Beyerle et al. describe the tasks of firefighters, the organization between professional and voluntary firefighters as well as current equipment.

Based on an analysis of past incidents they build a model that puts into relation the elapsed time after a fire started and the level danger it poses to humans (Beyerle et al. 1978: 181) that is still in use today to define firefighting reaction times (Schmiedel 2010).

In order to define a strategy for and optimize the use of fire engines, Beyerle et al. make use of that model and statistical data from past incidents about reaction times, damage to buildings and people and losses of life in cases of fire, in order to find the optimal distribution of fire stations and different types of fire engines across Germany. This quantification allows providing a cost benefit analysis for investments in firefighting.

Based on that research, the authors envision a modular firefighting engine concept to address different needs in firefighting with one platform across different models (Beyerle et al. 1978: 605).

While the research does not provide an account of the work on the frontline, it provides a remarkably extensive description of the firefighting organization in Germany of the 1970s.

Other, non-scientific sources provide records of modern frontline firefighting; their nature is various and they are difficult to be structured for technology design.

First, TV documentaries, present a snapshot of the conditions on the frontline. Here, the work is either reenacted based on the records and descriptions of real interventions (CBS 1994) or recorded at firefighting training sites (BBC 2010).

Second, firefighting online communities publish records of frontline practice. The interest of these websites is in sharing experiences among firefighters, often focusing on critical incidents (Feuerwehr Forum 2010, Firefighter Close Calls 2010b). The records are numerous but lack a structure in order to be easily accessible for technology designers, leaving an open space for this research.

Other researchers study the impact of new technology and management procedures and shows that changes affecting the identity might decrease firefighters' willingness to put their life at risk.

In her study of New York City firefighters Kaprow (1991) argues that their working culture and the characteristics of their dangerous work has for a long time prevented them from proletarianization, a trend where skilled labor is supplanted by semi-skilled or layman workers that can be observed in a variety of professions. Jobs are de-skilled and workers loose control and meaning of their job by changing production methods, the introduction of technology and thus novel work requirements, as it happened to printers, medical workers and even high professional jobs where managerial control took over the individual's responsibility.

For a long time, firefighters could resist that trend due to their special job. While other professions faced proletarianization, the firehouse remained an independent place and others respected the firefighting profession unquestioned. The mythical, heroic character of the work does not only contribute to the independence of the firefighting profession but also is a driver for people to start the dangerous job and put their life at risk to the benefit of the general public.

At the beginning of the 1990s, increased fire prevention regularities and fire fighting technologies in buildings have shown to be effective. The number of fires was declining and firefighters were asked to inspect buildings and to teach fire prevention methods. New managerial and safety measures changed the identity of the previously heroic firefighting profession.

Despite its resistance to outer influence before, Kaprow (1991) diagnoses that the closed system of firefighting has become subject of change processes, too. For the firefighters of New York City, such changes in their work practice go in parallel with the introduction of management processes and safety regulations, negotiations of unions for more regular working hours and official requirements to keep detailed records to evaluate productivity.

Such external factors infiltrate existing identity and work practice. While the managerial optimization might appear to bring about a positive rationality, transparency and safety to a previously closed system, firefighters worry that these outer influences might negatively affect their motivation and commitment–essential drivers for firefighters to do their risky job.

A firefighter states:

> We're all willing to risk our lives. We may be crazy … (but) if you break our spirit that will be the end. […] If they ever reach the day where they bring in a goddam time clock, which I'm sure some sonofabitch is thinking of; if they ever come up with computerized attendance … Why don't they just leave us alone, let us go on, like dinosaurs … If we believe that we are special, and society tells us that we are special … (and this is all) taken away from us, then we are going to behave like the rest of the factory workers. (Kaprow 1991: 101)

Concluding her analysis Kaprow (1991: 101) wonders if she is witness to "the last of the heroes, […] the end of magical work?"

Current frontline practice still needs to be studied in detail and the role of technology is highly relevant.

From the review of the existing work it becomes clear that the current practice of urban, modern firefighting frontline work has not been studied extensively or detailed. The review also shows that the impact of technology for firefighters is a crucial issue.

2.2 Digital Technology for Firefighters

Computing systems have been developed to support the command and control part of firefighting. Traditionally, systems have been developed to support top-down command and official hierarchies.

After this look at ethnographic studies of firefighting, I shall take a look at the current state of digital technology for the firefighters. The beginning make the system that have been developed to support the command and control part of firefighting, before I will take a close look at digital technology for the frontline. There is more research in developing command support systems than there is on systems for the frontline, as the conditions for command and control work are not as harsh and closer to typical computer uses. While this context of use is certainly different from the experience on the frontline, the approaches that people take can, nevertheless, inform this research. Current research on the design of IT systems that support command and control in firefighting operations specifically, and emergency response in general, proposes a number of different approaches to handle firefighter practice.

Turoff et al. (2004) take a top-down approach to the management of crisis situations and introduce a number of premises and requirements for the design of IT systems that support the management of emergency response across agencies. The work is based on an analysis of existing research results and on previous experience of a system originally designed in the 1970s to support the work of the U.S. Office of Emergency Preparedness, a predecessor organization of FEMA the Federal Emergency Management Agency. The system grew from solely supporting communication between a number of agencies in a crisis situation, to a group management system that allows to coordinate actions among several hundreds of users spread across the U.S.A. Laying out a future system, the Dynamic Emergency Response Management Information System, Turoff stresses the importance of roles that different actors take in an emergency response as a central entity for IT systems and lists a number of events and actions that in an IT system should be linked with those roles. The design envisions a system that centrally structures an emergency response operation and provides a model in which the current state of a large-scale emergency response operation is presented as a means to support the hierarchic structures in command and control work.

Deciding what information to provide is a central concern in the design processes.

Jiang et al. (2004b) present a field study and prototypes of a system to support commanders in managing firefighting operation. Based on interviews with firefighters, Jiang et al. (2004b) iteratively test three prototypes of a design of a large display command post system with features such as map display, resource allocation, location tracking of firefighters and notifications in case of sensor alerts from the individual firefighters. The central question for the researchers is to learn about the information that could be relevant and supportive to the incident commander and to look for undocumented tacit knowledge to inform their design. Even though the prototypes are rather simple from a technological perspective, interesting design questions arise when firefighters comment the designs. The challenge is to understand how much and how detailed the information that an incident commander receives should be. The design evolves from presenting a continuous stream of information to a system that only produces alerts in cases of problems that sensors detect, such as the notification of an almost empty air cylinder of a firefighter on-site. Also, firefighters state that there is no need for historical information on such display since it is used on-site and such historic information, which would allow them to trace back the positions of the firefighters, only becomes relevant after a mission has taken place. While the study mainly focuses on command and control tasks, there is also the need to integrate the firefighters working on the frontline.

For them, the system envisions sending messages to heads-up displays to show a visual alert when the commander decides to abort an operation.

Other research shows the necessity for improvisation in command and control and the need of computing system to promote such improvisations in decision support systems.

Using an archived firefighting operation from the Disaster Research Center at the University of Delaware, Mendonça et al. (2001) present a case in which the fire in a chemical plant was highly influenced by unforeseen events and required new strategies to react. During the operation, a crane, set-up to lift a roof, broke and soon after fire hoses froze due to low outside temperatures. Here, the incident commander improvised and solved the problem by ordering a forestry truck to remove the frozen fire hoses. These acts of improvisation inspire Mendonça et al. (2001) while designing a decision-support system for the Port of Rotterdam. They revise decision-support models and aim at supporting creative acts by understanding improvisation as an act of reworking knowledge in novel ways and by letting decision support systems provide alternative solutions to a given problem based on experiences and knowledge previously modeled.

Instead of applying decision-making theory as a driving force, there are also systems that make use of a sense-making perspective of the practice.

Towards the design of IT support for fire commanders, Landgren (2005) drops the concept of decision-support in favor of Weick's sense-making approach. His work is based on intensive ethnographic fieldwork with a Swedish fire crew. Moving from analysis to design, he presents a geo-information system that should support firefighters and especially incident commanders in making sense of the situation that they face. A prototypical system that runs on a tablet PC allows firefighters to see a map, satellite images and other geo-referenced information. In a field experiment, a fire crew uses the system during a staged intervention. As a result, Landgren shows that such system is able to support firefighter on their way to an incident in their sensemaking efforts. The system becomes an integral part of a complex social and collaborative practice where it is shared among firefighters in ways that their pre-defined distinguished roles might not have suggested.

Based on this work, Landgren therefore suggests to take a closer look at social practices of role models and calls for researchers aiming at designing ICT solutions to put greater focus on field experiments, highlighting the insights that such prototypical system can help to generate when it serves not only as a prototype but as a probe (Gaver et al. 1999) in understanding the social complexity of existing work practice. Continuing this work, Landgren (2006) takes a timely perspective on a firefighting intervention. He informs the design of an IT system that supports firefighters in building a record of the events during an intervention to support ongoing rescue efforts and post-intervention operation analysis. By the example of an intervention from the initial emergency call to the completion of the intervention, Landgren details the different steps in a firefighting operation and for each step shows the role of verbal communication that takes place over radio, phone and face-to-face. In this work, Landgren puts focus on the perspective of command and control and relies on transcripts or radio communication between incident commander and command control operators and interviews with commanders to inform his work. As a result, he suggests that verbal communication should be made persistent and visible in IT systems and can support the work of incident commanders. Realizing this idea, Landgren (2007) introduces a tablet PC system to a fire crew that allows seeing maps of the incident site and receive additional information of a building that is relevant to firefighters. The work presents a study of an initial prototype of the system that was designed to work as a triggering artifact (Mogensen and Robinson 1995) for the design process. The study makes visible the concerns brought forward by the firefighters that such system may interfere with their existing work practice and that they might have no time to use it or place to carry it in the case of a real intervention. Using the system, however, showed that they develop ways to integrate the novel technology into existing routines and that there are clear signals of opportunities and benefits for future use.

Following the sense-making approach, mobile phones become a supportive tool for incident commander of firefighting operations to share situated experiences.

Shifting the focus from the introduction of novel technology to already existing technology, Landgren et al. (2007) study the role of mobile phones in command and control of firefighting operations. In two large-scale accidents trains with chemical substances derailed and required a multi-agency response effort. From the empirical data, the use of mobile phones for communication and for making contact by means of a sharing mobile phone numbers, are important to the incident response. Landgren suggests that such existing mobile phone technology could be leveraged to manage incidents that are dynamically growing and envisions systems that provide information feeds to commanders and experts from different agencies using mobile phone networks.

Following that line of research and making available the use of already deployed ICT tools, the project Ideaviate (2010) introduces a system that allows emergency responders to use their mobile phones users to produce on-site videos and make them available as video feeds to command center operators as part of an emergency response operation. The users' phones are located via GPS so that the incoming videos can be displayed on a map in geographic location to each other. According to Bergstrand et al. (2006) the system has been introduced to three organizations, firefighters, paramedics and traffic authorities of the city of Gothenburg, Sweden. After a system evaluation during real incidents, users were positive about the system and praised its ease of use and its valuable contribution. While the system is reported to build a better bridge between command center operators and on-site emergency crews, firefighters also stated that it had yet to become a tool integrated in their daily routine.

Digital technology for the frontline available makes use of the breathing apparatus as a platform for introducing digital sensing and communication. Thermal cameras and navigation support systems are other examples of products available on the market today.

From this look at the systems designed for command work, I shall now try to shed light on the available systems for frontline firefighting and how designers rationalize their technological proposals for novel and improved systems and how systems developed have an effect upon existing frontline practice.

Dräger, one of the market leaders in the field of personal protection equipment (Dräger Safety 2008a), provides with its latest products for firefighters an integrated set of components for firefighters, with the breathing apparatus as the central hub (Dräger Safety 2010d: 13). Replacing the original barometer of the cylinder, the 'Bodyguard II' device (Dräger Safety 2010b) not only provides information on the pressure in the cylinder and the remaining time for operation, but also integrates a thermometer and a personal alert safety system (PASS) that triggers audible alarms in the cases when no movements are detected or a firefighter presses a panic button. The information about the current status can be transmitted wirelessly from the device to a new, digital control board that shows recent information from all the devices of a brigade (Dräger Safety 2010c). The new breathing mask of the system integrates a microphone and a speaker to enhance communication (Dräger Safety 2009b). It also can hold a 'head up display', a device with a set of LEDs that communicates wirelessly with the breathing apparatus displaying warnings in case the air pressure is low (Dräger Safety 2008b).

Apart from Dräger, several industry vendors provide thermal cameras to be used for frontline firefighting (Bullard 2010b, Dräger Safety 2010a, Honeywell 2010, MSA 2010). While the standard device is a handheld camera, some products can be mounted to a helmet and comprise a head-mounted display (Honeywell 2010) that in a test scenario, showed to decrease the need for communication between firefighters and thereby reducing the amount of air used at the frontline (Boyd 2007). Other cameras can transmit the image from the frontline to a mobile command center (Bullard 2010a).

As another digital system for the frontline, Dräger offers a system that comprises two kinds of components to track firefighters and support them in finding a way back. The ETR 1000 (Dräger Safety 2009a) are beacons to be placed by a firefighter on the way in the building and the FRT 1000 (Dräger Safety 2009c) is a device that helps to search for those beacons and can also be used to search for other firefighters carrying a FRT 1000 when they require outside help.

Besides thermal cameras in standard handheld and non-networked versions, none of these more advanced tools were already adopted by the firefighting organizations studied.

Technology-oriented research has been aiming at enhancing radio communication. Researchers refer to the practice as it is described in official guidebooks.

Radio communication devices are in use and constitute one of the most advanced technological artifacts on the frontline, making them an interesting topic of research. At CHI 2000, Cap et al. (2000) presented their work on improving traditional, analogue radio systems by addressing the technical problems that channels easily get overloaded and that half-duplex systems make it difficult to pass important information and prioritize messages among firefighters on the frontline and across different levels of command. The challenge for a radio communication design is in providing enough information to gain a general awareness for what is going on, but also in limiting communication so that command structures can be sustained. Camp et al. (2000) design and evaluate a radio system to tackle these issues. The system, on the one hand, makes communication easier among on-site crews through full-duplex communication and, on the other, equips commanders with both a full-duplex communication down and a half-duplex communication up in the command hierarchy and also creates an 'audio horizon' that allows commanders to receive radio messages from a number of higher and lower hierarchy levels to gain situational awareness. Throughout their proposal, the designers rationalize their concept using official description of the procedures issued by firefighting authorities.

As other research shows, failing communication systems have indeed been a cause for the death of firefighters in a number of incidents. Thiel and Stambough (1999) analyze a number of incidents to inform firefighting practice and technology design and show that the problems with current radio devices are twofold.

On the one hand, radio devices have technical limitations and problems of usability. Interference and shielding effects of building structures limit the indoor use of radio technology. Also, devices deployed mostly support half-duplex communication so that communication channels can be blocked by transmission. Additionally, devices used in firefighting are not especially designed for the job on the frontline but are standard equipment used for a variety of purposes. This technological misfit makes devices difficult to use for firefighters in combination with their protective clothing and breathing apparatuses and in the extreme conditions of a firefighting operation. Technical problems and the low usability of the devices has been found causal to injuries and deaths of firefighters (Thiel and Stambough 1999).

On the other hand, problems in radio communication are related to social issues. Problems arise when firefighters do not follow a strict radio discipline and protocols as an answer to the limitations of a half-duplex communication system. In these cases important messages cannot get through. Also, firefighters need to ensure that their voice gets heard despite the limitations of the microphones and need to give clear statements to be understood. Problems also arise when firefighters do not report problems early enough to their superior commanders. Here, a firefighter or team that is assigned to a particular task has to realize that the problem at hand cannot be solved and report this up the command line. Such statements can conflict with the image of a heroic, strong firefighter, who is sent to solve a mission, and make the firefighter report too late. In other cases, a team may lack an understanding of the large context and might therefore ignore a certain detail relevant enough to report, which would be important knowledge within the larger scope of the entire intervention. As with the technical limitations, user behaviors and cultural issues concerning radio communication have been reason for a number of tragedies (Lave and Wenger 1998).

Following the guidebooks on firefighting hierarchies only, Camp et al. (2000) do only partially address the complexity of the problems with radio communication.

Other researchers take out certain aspects of the frontline work and run experiments to understand the practice, they thereby, however, ignore important aspects of the work.

Supporting firefighters by means of computing technology has also become a topic of interest for robotics research community. (Naghsh et al. 2008) presents an approach towards robotic swarm support. In the envisioned scenario, firefighters working in large warehouse facilities are supported by an intelligent swarm of robots in their navigation tasks on the frontline. A study with firefighters led to a number of conclusions: First, robots will either function as teammates or bystanders, following the classification by Scholtz (2003); second, dedicated robot experts are required in different roles to control and monitor the robots from remote stations while people in the regular command chain can benefit from snap shot information of the system; and third, the robot swarm itself needs to form a group around a firefighter on-site gives unambiguous navigational directions and notifies the firefighters when there are obstacles.

Building on this work, Naghsh and Roast (2008) present a study with a visual guidance display. An array of LEDs was mounted to the helmet of a firefighter displaying either a set of encoded commands or a directional light showing the firefighter a safe direction as computed by the robot swarm. An evaluation of the interaction mechanism, using a wizard-of-oz facilitator to generate directional guidance, showed that firefighters had a strong preference for a direct guidance display with a very limited resolution in 45° steps and also suggested the system to offer commands and thereby work like GPS navigation systems used in cars. When relating the experiment to real firefighting operations the firefighters stressed the fact that they need reliable navigation information and that compared with the traditional navigation using the walls, the visual display did not constitute a bearing that they could trust.

The authors conclude that firefighters operate with clear communication channels and that this characteristic may be expected from the technology as well. They note that some firefighters relied on their existing navigation practices and simply ignored the new technology. Also, the authors describe the limitations of their setting since in the context of research it is very difficult to artificially create a setting that mimics effectively the conditions of a real firefighting operation.

In less user-centered approaches, technology designer use firefighting as a scenario to rationalize the need for a certain technological development and leave out demands of real-world conditions.

Jiang et al. (2004a) focus on the problem of scarce information during firefighting operations and propose a peer-to-peer mobile computing system that supports firefighters indoors in getting contextual information. "Firefighting is making a lot of decisions on little information", Jiang et al. argue (2004a: 87) and, as previously described, radio communication can be difficult in noisy environments, with limited communication channels and in large building that may shield radio waves.

In the prototypical application, a number of PDAs are connected via a peer-to-peer wireless network. The software architecture of the system ensures that information is shared between the devices opportunistically, so that certain parts of the network can collapse while others remain functional. The system is proposed to issue automatic and manual warning messages to firefighters on-site, in the automatic cases based on readings from temperature sensors embedded in the mobile devices as well as sensors pre installed in buildings and sensors measuring the remaining oxygen level. A rule engine defines for whom the reading is relevant and issues the message to the affected firefighters through the network. These technological concerns were in the center of attention.

When presenting the system to firefighters, they were positive about the system and especially valued the short messages issued by the system and the peer-to-peer technology that facilitates networks in areas where radio communication may fail. They were, however, also concerned about the ruggedness of the system and stressed the fact that they would prefer a system that does not solely rely on sensors embedded in buildings. Firefighter wanted to remain in control, a firefighter said: "The most effective tools for us are always those we can directly access and maintain" (Jiang et al. 2004a: 102).

Researchers identify shortcomings in the existing frontline practice and build tools to overcome them. The proposed designs, however, face technical and social acceptance problems.

Indoor navigation is another vital task for firefighters during operations in buildings full of smoke. Under poor visual conditions, orientation and way finding are crucial for successful emergency response and mistakes are dangerous and have shown to be causal for a number of accidents.

In an attempt to support firefighters in indoor navigation, Steingart et al. (2005) perform interviews and identify shortcomings of the existing practice. They present the results of interviews with 60 firefighters in Chicago with regards to technology acceptance, existing equipment and concerns towards digital health monitoring.

Learning from that material, Wilson et al. point out that firefighters frequently base their decisions on "guesswork" (2007: 1). Firefighters "guess where the most safest and most effective place to enter the building is", they "make a best guess of where the fire started and where it is travelling" (Wilson et al. 2005: 103). In contrast to this "guesswork" the envisioned system aims at triangulating firefighters' locations with high accuracy and showing the positions on a map to the firefighter commander and to via a head-mounted display to the firefighters on the frontline.

To generate position information, sensor beacons are mounted to fix locations in a building. A map display can be used by the firefighter on-site, via a head-mounted display in the mask. Wilson et al. (2005), in particular, focus on the physical and ergonomic requirements when using head-mounted displays in firefighter operations and discuss the technical challenge of integrating them into existing breathing masks. Simulating traffic lights, the beacons will provide visual indications to tell the firefighters if a path is safe or not, as a result of the calculations from the readings of the sensor network. The proposed design relies on pre-existing maps of building structures and argues that such maps will become or already are mandatory for critical infrastructures. In addition to the pre-installed sensors, the firefighter alternatively might also distribute the sensor as a future option.

As the authors point out, the system design faces challenges.

From a technical perspective, providing a system which is able to operate under frontline conditions shows to be a difficult task. A requirement for their system the need to provide accurate information in order to be trustworthy; misleading information might be fatal. Providing this accurate information is a great technological challenge especially in the unstable environments of firefighting operations and Wilson et al. summarize that “there is much work to do in raising the performance to a usable level for real incidents” (Wilson et al. 2007: 7).

From a social perspective, firefighters express their resistance towards the system. Letting alone their technological vision and the sensor network proposed, the authors also point to the skepticism of firefighters towards the proposed system. Without much detail, they note that for firefighters “there are ‘tried and true’ ways of handling emergency incidents” and conclude that “an immediate revolutionary change will not be adopted and will not work”, instead “implementation needs to be gradual”, a

> successful implementation of an advanced information technology system for emergency response will require gradual enhancements to the currently used systems.” (Wilson et al. 2007: 7)

While the authors, in this case, understand the close binding of firefighters with their existing practice as a problem for the introduction of their novel technology; it also can be interpreted as a call for an ethnographic design approach.

In summary, the example of supporting command and control with IT reveals a tension between a focus on hierarchic structure and roles, on the one hand, and a focus on the improvisational, situated character of the work, on the other. There is the need to support technology designers in understanding firefighting frontline practice and integrating such understanding in design processes.

As the review of the research shows, the presented systems supporting command and control show that the different views of decision and sensemaking approaches, each emphasizing different aspects of the work. Researchers approach the field with a theory in mind and both find aspects in the work that support the arguments.

Designing computing systems for frontline firefighters is an open challenge. The complexity of the design task requires a detailed understanding of current practice, which, as shown in the previous section, does not exist.

Beyond descriptions in official regulations, novel technology is situated in the actual work practice. Handling this complexity in design processes is an open challenge, too.

2.3 Design as a Transformation of Configurations

In the field of architecture, the general problem of understanding a specific context for the purpose of design has been central to architect Christopher Alexander.

Letting alone firefighters' frontlines for a moment, the general problem of designing artifacts that fit a special context is not new or unique to the field of HCI. The question "what it means for a system to be 'good' in a particular context" (Harrison et al. 2007) that I have cited before is not an issue for computing systems only. Instead, we live in a world that to a large extend is the result of human design. While certainly not all the designs we encounter have paid special attention to human practice or aimed for creating human-artifact configurations that are good, or reflected what it means for a certain environment to be good, there is some work that specifically has dealt with those problems.

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.; he wants to answer the question "Under what circumstances is the environment good?" (1999: 74)

Design is about putting things into shape and creating form, and about understanding contexts. The mission of design is to achieve an optimal fit between context and form.

According to Alexander, creating form is the duty of the designer. "The ultimate object of design is form." (Alexander 1964: 15) Form, in its most general sense, is the result of actions taken by designer. Here, 'form' does not only include the physical shape of things, but also refers to all the characteristics of the thing that is in the process of being created, its appearance but also structure, inner workings and other features that designers might give to a thing.

Form, as the result of design, cannot stand in the center of attention separated from its context, form is created and has to be created in a given context. Every form that the designer creates resides in a context that is composed of a manifold set of properties. The context reveals problems that the form can help to solve. The context reveals requirements that the form can help to meet. The context produces opportunities that the form can help to nurture. The form interacts with its context. The designer's attention therefore cannot focus exclusively on the form, disregarding its context. Understanding the context thoroughly is therefore crucial for the designer.

The properties of the context support the designer in finding the form that fits the context (Alexander 1964: 18). Learning about the context helps to build an understanding of what actually is or should be within reach of the designer's effort. Learning about the dynamics of the context of the interaction helps to create sustaining forms. Learning about the individual parts of the configuration supports the designer in forming an overall perspective.

The problem of design is to achieve an optimal fit between form and context so that the form helps the context to achieve a higher level of evolution.

Especially professional designers have greater problems in designing fitting artifacts, as they are not an immediate part of the human-artifact configuration.

As described by Alexander (1964: 36ff), the professional designer is usually not the user of her design and therefore lacks an immediate feedback of the resulting artifact. Projects are more complex and are therefore more difficult to iterate. A rapid development in society requests for novelty and brings about significant technological advances. This deprives the designer of the possibility to rely on wisdom rooted in culture and tradition. The professional designer finds herself confronted with a limited understanding of the context, a form that is more difficult to change and both context and possibilities for forms highly dynamic and ever changing.

Alexander argues (1964: 63) that designers, lacking a solid grounding, tend to rely their design decisions on concepts that are often too abstract and general and mostly lack an understanding of the interactions of the many aspects that a context comprises. They form a world of their own distant from the problems of the real world. Such 'conceptual dogmas', as Alexander (1964: 70) calls them, trap the designer and hinder her in finding solutions to the problems at hand.

The view of design as a task of optimizing fit between form and context, does not present the complexity of achieving this fit.

While one might reason that the designer simply needs a description of the requirements, a specification of the shape of the context in which the newly created form needs to fit, this shows not to be a simple task. The division of the designer's world into form and context and the description of the design as the task to make the form fit the context might seem trivial, yet, in a more thorough analysis, the assumptions made, appear to be not necessarily compulsory and can be called into question (Figure 3).

First, specifying context is difficult if not impossible. The border between what is considered form and what is considered context might not be as clearly defined as the theory suggests. Some parts of the context might clearly remain context, other parts, previously considered context might become part of the form, or remain vague. Indeed, the decision of what it being treated as given context and what will become part of the designer's consideration is part of the design, too. Defining the border or its acuity is actually another task to be handled by the designer it is a matter of definition that the design has to make. Alexander speaks of the "designer's sense or organization" (Alexander 1964: 18) to define this relation. But even if the border is clearly set, the problem is that most contexts cannot be described adequately. Social contexts are difficult to be described in full and it is therefore difficult to design a well-fitting form following context specifications.

Second, both context and form might not be as stable as the theory suggests. Interactions between the form and the context might cause the context to change, so that the requirements, problems and opportunities might change. Also, the forms and contexts are not free from timely effects. People develop and appropriate forms. The context itself is part of and influenced by other contexts. In summary, the overall system is not necessarily stable; it changes with the time.

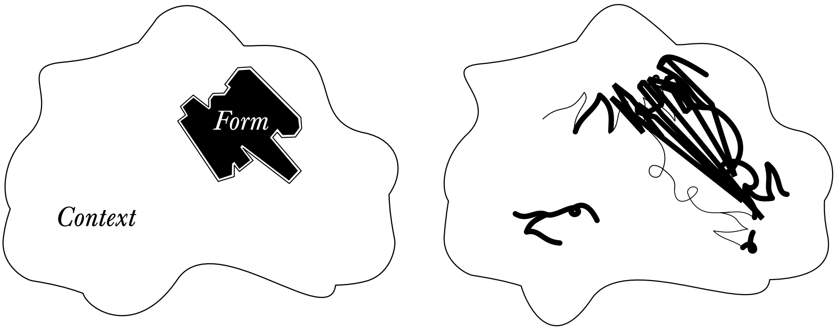

Figure 3: The view of design as a task to make a form fit a context (left), ignores their interaction, timely effects and the difficulty of specifying context and form (right).

Third, there might not only be one context and one form but multiple instances of multidimensional contexts and forms that overlap and interact across different levels. Hence, the designer is seeking to evolve the entire system comprising all the forms and contexts to a new stage of development.

Yet, even with a general, a priori definition of the border between context and form missing, with context and form related and intrinsically non-static and with the designer seeking to address the whole rather than the detail, the relation and interaction between what is being created and what is already, remains a fundamental interest of design.

Design is a wicked problem and cannot simply rely on an analysis of a context followed by a mechanical selection of solutions that match the constructed requirements.

In their seminal work "Dilemmas in a General Theory of Planning" Alexander's colleagues, Rittel and Webber (1973), argue that traditional scientific methods fail for the process of design, due to the nature of design problems.

Traditional methods propose a focus on increasing efficiency and share the idea that a thorough analysis of the problem will open a straight path to the solution. Rittel and Webber (1973) acknowledge that this methodological approach has been widely successful and has increased the comfort and efficiency of life for many–it has been key to the development of modern society.

This approach, however, works only for problems that Rittel (1972) calls 'lame'. Lame problems are easy problems not in the sense that they are necessarily easy to be solved but they are easy in the sense that they can be well defined, their goals can be clearly formulated and the actions to be taken can be derived from a thorough analysis of the problem.

For wicked problems, on the other hand, traditional scientific design methods fail, as they are not able to deal with the inherent complexity of the problem. An entirely rational approach cannot be applied to wicked problems as it opens an infinite loop of considerations without coming to a design rationale (Rittel 1972: 392).

Following Alexander's understanding, design is a wicked problem.

> [W]e might almost claim that a problem only calls for design (…) when selection cannot be used to solve it. Whether we accept this or not, the converse is always true. Those problems creating form that are traditionally called 'design problems' all demand invention. (Alexander 1964: 74)

Wicked problems cannot be defined definitely. "Learning what the problem is IS the problem" (Rittel 1988: 2). They have no stopping rule, solutions to them are not true or false only better or worse, it is hard to test the outcome of a wicked problem and the solution itself affects the system significantly in such a way that iterations are difficult to perform. Wicked problems are unique and intertwined, it is difficult to distinguish between symptom and cause (Rittel and Webber 1973).

Describing the nature of design problems, Alexander concludes that "a design problem is not an optimization problem" (1964: 99).

To understand the human-artifact configurations we design, we need to change our understanding of the world away from the mechanistic model introduced by Descartes that is distant from human experience.

If the fit between context and artifact results from a complex, interacting configuration, how do we know that a design process was successful after its completion? How do we know if a design process resulted in a better or worth configuration than another process? What are the criteria to understand design results?

Alexander (2002a: 1) aims at forming an approach adequate to understand "the beauty and the life of buildings." He argues that …

> our modern mentality–our way of looking at the world–makes it hard, or impossible, to come to grips with the facts as they really are. Issues which were straightforward in other ages–such as spirit, for example, or that life can exist in a stone–are inadmissible for us. (Alexander 2002a: 2)

Reason for this is inability to deal with these issues is the adoption of a mechanical world view that can be traced back to the work 'Discours de la méthode' written by the philosopher Renè Descartes in 1637. In this work, Descartes–besides making his famous "cogito ergo sum" statement– introduces what has become central to the understanding of correct reasoning and the seeking of truth in the sciences. In the second part of 'Discours de la méthode' Descartes suggests to divide any research problem into distinct parts so that they can be understood in their limited complexity as a simple machine and then, based on the understanding of the parts, gradually composing a mental model that allows explaining the greater complexity of the whole. For this process of seeking truth, Descartes (1637/2008) asks "to comprise nothing more in my judgment than what was presented to my mind so clearly and distinctly as to exclude all ground of doubt." Beyond dispute, this mechanical world view has cleared out prejudices and has been at the core of human advancement and the understanding of the world today (Alexander 2004: 12-13).

Alexander, nevertheless, criticizes that humanity more recently has confused what was originally invented as a method for seeking scientific understanding with reality itself. Reality is believed to function as the mechanical model suggests. This understanding, on the one hand, eliminates the image of subjectivity and self-awareness. Alexander argues that "[t]he picture of the world as a machine doesn't have an 'I' in it." (Alexander 2002a: 16). On the other hand, this understanding loses a "definite feeling of value" (Alexander 2002a: 16). Taking the mechanistic idea as reality therefore "tells us very little about the deep order we feel intuitively to be in the world." (Alexander 2002a: 16) While scientists traditionally argue that only models as suggested by Descartes may be true or false, Alexander suggests that also "statements about relative degree of life, degree of harmony, or degree of wholeness–in short, statements about value" (Alexander 2002a: 17) can be equally true or false.

Looking again at Descartes' work it becomes clear that Descartes himself clearly understood the limitations of his proposed method and the distinction between the method and reality. While in Descartes' view a mechanical, machine-like model is for instance of great help when trying to understand humans' functions of the bloodstream and the inner organs, resembling a human in a machine would not make the machine human or alive, since the complexity and interactions among different parts are far greater than the model may be able to explain (Descartes 2008: Part III).

Following this line of thought, Alexander introduces his constructivist theory to architecture. He presents his approach as an alternative to Descartes' approach, Alexander explains:

> In any situation where the relevant facts have to do with things that can be viewed in a machine-like fashion, the method of Descartes is best. But in any situation where the relative wholeness of different systems is the most relevant issue, then the method of Descartes, by itself, will not work. We then need a method which can explicitly, and objectively, recognize the relative degree of wholeness in different systems. (Alexander 2002a: 369)

Alexander's design method suggests understanding what makes an existing configuration of practices and artifacts work and to evolve this existing configuration in organic, structure preserving design processes.

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 geometry of human configurations and of our relationships to the land and to our own private and public persona. That means that the environment, viewed as a microcosm, must consist of many small relationships among things. And these highly personal relationships exist at a variety of scales. The environment will come to life for us if, and

> only if, it is built 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. That is because it is, above all, a human endeavor. In contrast, the less well we succeed in fitting our environment to the small details of the social and human relationships of our society and culture, the more misfitted we shall be in our world and the more unfortunate we shall continue to become. 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, realistically, the physical relationships which, when built into the fabric of our environment, will nourish our social and emotional lives. (Alexander 2009, 00:27:06ff)

With this statement, Alexander provides a concept for how to relate human practice and design.

To understand existing configurations, Alexander proposes the concept of pattern languages. Patterns capture aspects of social configurations and, in their interaction, describe why complex configurations work.

Alexander argues that "every place is given its character by certain patterns of events that keep on happening there" (1979: 55) and that these "patterns of events are always interlocked with certain geometric patterns in the space." (1979: 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 or class of environments." (2002b: 345) (Figure 4, left) To support the design process, the designers need to look for patterns that describe configurations that hold the "Quality Without a Name" or a "Living Structure" characterized by a "freedom from inner contradictions" (1979: 26). The quality that Alexander seeks to capture in pattern form "makes us feel comfortable. Above all it makes us feel alive when we experience it." (2002a: 36) It 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: 37) Each of Alexander's patterns describes a problem, the solution and the context in which both apply. In the description of the context, Alexander creates the relations between the patterns and thereby shows their interaction and dependency, a pattern language results. Alexander underlines the importance of these links and the interac-

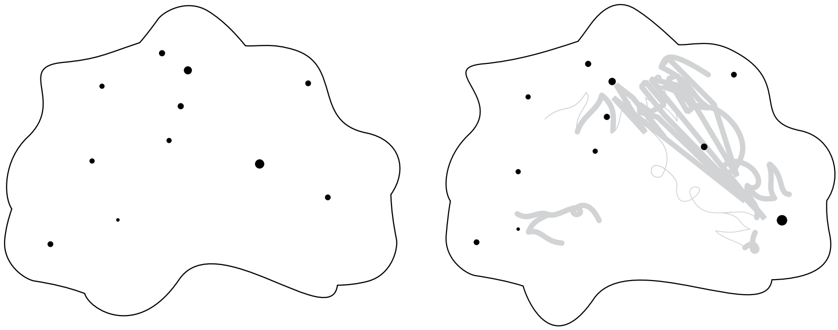

Figure 4: For Alexander, any configuration contains interacting centers (left) that can be described in a pattern language. The pattern language supports structure preserving transformations in which the centers and their interactions evolve (right).

tion between the patterns. A pattern "not only describes a recurring center, but also describes a relation between other generic centers." (2002b: 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: 3)

Especially in his later work Alexander (2002a, 2002b, 2004, 2005) reflects on the pattern language concept and underlines the importance of the links and the interactivity between the patterns. While we can think of different entities within a configuration, their boundaries are not easy to be defined and appear blurred when closely studied. Therefore, Alexander talks of the different entities comprised in a system as 'centers' that make up the whole with their interactions, connections and overlaps. Such centers do not exist alone, they are "induced within the wholeness and come from the wholeness" (Alexander 2002a: 87). Alexander explains:

> However, my attempt to catch the solidity of these entities as the fundamental elements of order never really came out right; it never worked as the fundamental notion. I began trying to get this out straight in the later versions of 'A Pattern Language', where I noticed that even the entities which formed a pattern were in effect patterns, too, so properly a pattern was not a pattern of entities, but a pattern of patterns. This brought the entity concept into doubt by stressing the fact that the things which ap-

> peared to be entities were fluid, not fixed, not bounded, not really 'things' at all. All this only finally became clear to me about ten years ago when I finally understood that all the troublesome entities, which were so important as the building blocks of nature, were not truly bounded entities but were in fact non-bounded centers: Centers of influence, centers of action, centers of other centers–centers of some kind, appearing in the seeming mass of the wholeness. (Alexander 2002a: 107-108)

Applying this new perspective, Alexander explains the relation between centers and patterns: Centers become real-world instances of patterns. Or, put differently, patterns are blueprints for centers.

> One might say that every new pattern defined under the theory of pattern languages is a rule for creating a certain type of (new) living center, needed and appropriate in a given range of contexts. More precisely, one may express the relationship of the two theories like this: 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 or class of environments. Further, a pattern not only describes a recurring center, but also describes a relation between other generic centers. But it must be remembered that the pattern describes a generic center, not a particular center. In this sense the pattern is not so much like an element in an erector set, but more a rule for making a certain kind of center capable of making an infinite number of particular centers of the same type, whenever they are needed. (Alexander 2002b: 345)

To evolve existing configurations by design, Alexander calls for a gradual, structure preserving process.

Inspired by organic growths processes in nature, Alexander (2002b: 20ff) shows that in nature systems have to grow, they unfold, they emerge. The organic growth process is a model for design that aims at producing living configurations, as otherwise fabricated plans do not generate the living structure (Alexander 2002b: 185).

> What process can accomplish the subtle and beautiful adaptation of the parts that will create a living architecture? In a certain sense the answer is simple. We have to make–or generate–the ten thousand living centers in the building, one by one. That is the core fact. And the ten thousand 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 oth-

> ers, and the ten thousand centers then–if they are truly living–must form a coherent and harmonious whole. (Alexander 2002b: 3)

Transformations in existing configurations should preserve the existing structure. Alexander therefore 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." (2002b: 52) The design process should be iterative, gradually molding the new shape and retaining or evolving existing centers (Figure 4, right).

> The idea is that a structure-preserving process on the one hand transforms and preserves structure and on the other hand the idea that this structure-preserving transformation then also enhances the whole. (Alexander 2002b: 255)

Alexander characterizes this design process as careful and personal, a humane process between designers and users.

> It is a true process, 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. This is not trivial, but deep; sincerely related to human feeling; and not predictable in its end-result, because the end-result is not the goal. (Alexander 2002b: 9)

This call for understanding design as a structure preserving transformation makes patterns and a pattern language an integral component of this process, as a pattern language is Alexander's means to describe a working configuration. Alexander makes use of the pattern language as a boundary object (Star and Griesemer 1989) that for users and designers may have slightly different meanings but is common enough to work as a means of translation that allows discussing potential changes, that serves as a checklist, that conserves knowledge and brings it to new contexts.

Alexander provides an understanding of design relevant to the design of ubiquitous computing for its ability to understand human configurations.

Returning to the original topic of this work, the question is how Alexander's work in the field of architecture relates to the problem of designing ubiquitous computing for frontline firefighters.

Ubiquitous computing, in its close interweavement with human life, as discussed in the introduction, clearly has a social dimension, too. Computing technology exists in interaction with social contexts. Harrison et al. (2007) call for designers of technology to understand "what it means for a system to be 'good' in a particular context" and draws a link between existing practice and values to the introduction and design of computing artifacts. Understanding the configuration of a given context therefore is important for the design.

While the types of artifacts created differ in the two fields, the concern to build artifacts that respect human values is the same. Alexander provides a theoretical framework and moral grounding in human experience for respecting social configurations and human behavior when designing artifacts.

The introduction of ubiquitous computing to frontline firefighting requires a structure-preserving process.

While one may argue that Alexander's approach, rooted in existing configurations of the past, may not allow for sudden technological advances that revolutionize existing practice and is therefore unsuited for the invention of technology for a context where there is no computing support today, one has to remember the culture and nature of frontline firefighting.

First, frontline firefighting is a safety-critical work where failures of technology or mistakes in the usage pose a risk for human life. As of today, firefighters know how to deal with fire, and in most cases they do so safely. Novel technology needs to be trusted and will only be adapted if the firefighters are convinced that it is safe to do so.

Second, the primary focus of the work on the frontline is to prevent harm from people and buildings, to bring people out of danger and to extinguish fire. These primary activities are unlikely to be replaced by ubiquitous computing. Therefore, technology has to fit closely the existing practice.

Finally, firefighting is craft, an existing practice that is based on long experiences. Preserving the identity and culture of firefighting is crucial to ensure that firefighters continue to be willing to put their life on risk to the benefit of the general public.

A structure preserving process, as suggested by Alexander, is therefore essential when designing ubiquitous computing support for frontline firefighting.

Different from Alexander's work, for the design of ubiquitous computing for frontline firefighters the spatial configuration is not part of the design process and there are almost no examples for digital technology to draw from.

While both the general approach and process of Alexander's work appear to be in-line with the purpose of this work, there are some important differences where Alexander's approach cannot be transposed easily.

First, the architect shapes the physical spaces in which human activity takes place. The ubiquitous computing designer, on the contrary, creates artifacts that become parts of the space and while they often change practices directly, the influence on the physical space partly is usually not as direct.

Second, for the field of architecture, Alexander bases his work on thousands of years of architectural experience and both houses and physical spaces that have been created over many years. He can easily compare one solution to another and refer to the daily human experience as a means to assess the configurations. At the frontline of an intervention, however, only little computing support exists and the work context is very different from daily experiences.

Despite these differences, firefighting frontline practice forms a configuration that future tools need to consider. A language of patterns of human activities at the frontline shall transform the existing practice into a design space for computing support.

When understanding the context of frontline firefighting as a social configuration formed by long experiences and culture, a pattern language of human activity can make the practice accessible for technology designers in interacting patterns of human activity.

While such pattern language cannot draw on existing, successful artifacts, it can open up human activity, the social configuration to the designers and thereby describe a design space.

Given the lack of the spatial design, this research has to understand the physical context as mostly given and to take into account not only the relation between space and human activity but also include other aspects and artifacts such as existing routines and the tools that firefighters use. Also, given the lack of existing examples and previous knowledge for computing support in this special environment, this thesis has to make the creation of experience and intuition a part of the research and needs to convert knowledge from the existing artifacts and practices to the design of ubiquitous computing.

As discussed in the following chapter, pattern approaches inspired by Alexander have been applied in the field of HCI, as a means to make available the results from ethnographic studies and informed design processes in various ways (Crabtree et al. 2002, Erickson 2000a). These investigations do not provide patterns as technology-oriented construction rules, in the way Alexander originally does, but they share the same conceptual goal. Pattern languages aim to answer the central question Alexander (1999: 74) poses, namely: “Under what circumstances is the environment good?”, that should further drive this research.

2.4 Pattern Research

In the field of architecture, the evaluation of Alexander’s work is controversial. Architects, who try to design buildings by directly following Alexander’s patterns, derogate the work, others, who follow the procedure and do fieldwork, present successful examples.

With the philosophical underpinnings and the overall aim of Alexander in mind, one may ask if and how pattern languages actually supported design processes and if and how a pattern language may support the design processes this thesis focuses at, namely the design of ubiquitous computing solutions for firefighter on the frontline. To start answering these questions I started out by looking at the implementations of pattern languages in the original architectural and urban planning context that Alexander had in mind and then compare the original concepts to pattern research in the field of computer science.

Some architects argue that Alexander's pattern language does not work for designing buildings. When asked in a 2009 panel discussion on Alexander's work about the presence of Alexander's in today's American architecture schools, Michael Mehaffy, a past Director of Education, Prince's Charitable Trust and Research Associate at the Center for Environmental Structure, Berkeley noted, that it is "non-existent", and Robert Campbell, of the Boston Globe's Architecture Critic added:

> I have had students who tried to take 'A Pattern Language' and used it as a means, a book of rules, of how to get a building, and it does not work. […] [Alexander] is a magnificent observer of life and a drawer of conclusions about life. He is not a system maker, it seems to me. (Campbell et al. 2009)

Interestingly, Alexander's 'A Pattern Language' is one of the most read architectural books, yet it is largely neglected by architectural schools (Saunders 2002: 1). In his review of 'A Pattern Language' Saunders (2002: 5) describes that the many rules in the patterns cannot be realized at the same time. The architectural community also criticized Alexander's method, as applied by in 'A pattern language', to be unscientific. Saunders (2002: 4) argues that a "major weakness in A Pattern Language's utopianism is that many of its rules are not based on hard critical thinking or careful research." Saunders describes Alexander's work as a dreamful picture that trusts goodness in people but does not face up reality. And indeed, Alexander's patterns cite various other works but do only rarely link back to results from original research that would apply the methods described by Alexander. Saunders concludes that one should not treat the book as a bible or instruction manual for creating towns or buildings but instead make use of it as a checklist and reminder to architects. The value of 'A Pattern Language' is in its detailed description of certain phenomena.

> Nowhere have I read an articulation as convincing as Alexander's of how one might create a 'sacred space'–with a connected series of 'nested precincts' that become progressively more private and end in a sanctum sanctorum. (Saunders 2002: 6)

In contrast to this criticism, there are indeed examples, where pattern languages have successfully supported architectural design processes.

The first example presents a case in which a pattern language, derived from a large base of empirical data, could affect the policy making for New York City's plazas and provided a thorough view on the different aspects that make such gathering places work in both big cities and small towns. In the 1970s Whyte (2001) and his team were conducting extensive user research on the quality of plazas and other gathering places that had been promoted by local policy making. Specifically, they were interested in why some of these places seemed to be popular with the people and others were not. They wanted to understand 'the social life of small urban spaces', as Whyte phrased it. Through observation and interviews, time-lapsed filming and photos, quantitative and qualitative data they were trying to provide the information that could lead politicians to optimize the policies for urban spaces in such a way that more alive places would be created.

The patterns that Whyte describes are multifold. He looks at the sizes, types and arrangements of sitting places, the impact of sunshine, wind and trees, the benefits of on-site food and the structure of the surrounding streets. His findings include social issues such as the problems related to homeless and poor people in public spaces, the need for security and the role of guards and other relevant issues such as the maximum capacity of a sitting place. Besides the work on patterns, Whyte also establishes several criteria that help to judge if an urban place is alive. He not only counts the number of people in an urban space but also suggests checking the male-female ratio, as a higher female proportion suggests a better place, and to look into peoples' faces and to see whether they fully engaged in discussion, as a better place makes people stop and talk. Whyte's pattern language brought a deep insight in why some urban places work, while others do not. It directly impacted urban design policies.

The second example presents a case in which a pattern language helped the residents of a small town to become active participants of an urban planning design process. Hester (1993) presented an urban design project in the U.S. city of Manteo, NC where he looks for events in places highly valued by residents, to inform an urban planning process that should attract more tourists to the city and yet preserve and build on their valued lifestyle. The local newspaper published those 'sacred places' and 'sacred landmarks' in a map of the city (Hester 1993: 278). In the following, those patterns were used in a collaborative urban planning process that involved the residents. Although Hester himself does not refer to the works of Alexander, this urban design project represents a successful creation of a pattern language for a specific need. He successfully accomplishes to build a pattern language and to identify local entities in the town that are alive, important to the residents and therefore should be preserved. The pattern language becomes an important tool in the design process–it gives the residents a voice when talking to the city planners and outside consultants, a language that they used to argue for and against new planning projects. This is resembled best in the quote of a resident who commented on a design proposal by a consultant that was rejected. He said: "Those consultants were from out of town; they just never heard of our 'Sacred Spots.'" (Hester 1993: 292) Here, the pattern language has become a formal means for the residents to express their needs and reflect on and to discuss about the impact of changes to the social and spatial configuration of their city.

Interestingly, these successful examples are much closer to the way Alexander himself makes use of his work than the process described in 'A Pattern Language'. Indeed, he provides numerous examples of how to create and make use of the pattern language. After all, he has designed more than 300 buildings, besides his reputation of being the first person who brought theory to architecture (Campbell et al. 2009). Noteworthy, Alexander does not use patterns as standard solutions; he uses existing patterns to inspire designs but in each case creates a new instance of a pattern language that respects the local needs. His concepts build on the users expectations and their imagination of good situations. In a hands-on approach, he takes the residents to the places of the future building to ask for their ideas of a perfect design, based on their past experiences. In this way, the real context of the future building provides the physical frame for working on design questions. Alexander reports on the design process of building a farmhouse for a couple:

> 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. (Alexander 2002b: 355)

In Alexander's work there is a great care for details, he does not apply standard solutions. Constructing a building often involves handwork. Alexander, for example, discusses the construction process of a shelter for homeless people in San Jose, California. In a letter to a local newspaper Alexander reveals some of the detailed considerations during the process of construction. Particular gates, tiles, benches, concrete trusses and archways received a great level of attention in an iterative process. The selection of colors receives careful thought as well as the design of rather small elements such as a kitchen pass-through or the capitals of columns. Small components of the design are not mere functional elements but understood as individual centers that can hinder or support the process of creating the living structure (Alexander 2005: 127-131).

The successful examples by Whyte, Hester and Alexander show a common concern for creating positive spaces, a concern for using design as a means to produce situated, positive change. On the one hand, there is a concern for human activity, for what people are doing, for understanding when an environment is good. On the other, there is a concern about the relation and interaction between the physical space or building structure and human activity. In this sense, pattern languages of the interaction between human activity and building structure provide guidance to the architect. Pattern languages in architecture help to explain how design can impact human activity in a way that strengthens life in configurations. For architecture or urban planning, pattern languages provide a direct value-laden link between spatial configurations and human activity.

In the field of computer science, the software engineering community has adapted the pattern format and the idea that patterns can help solve reoccurring problems. Despite their popularity and success, software architecture patterns do not share Alexander's aspiration.

In 1995, Erich Gamma, Richard Helm, Ralph Johnson and John Vlissides brought Alexander's work on architecture to the world of computer science (Gamma et al. 1995). In their book 'Design Patterns: Elements of Reusable Object-Oriented Software' they transpose Alexander's concept of architectural patterns to architectural concepts for object-oriented software.

Ignoring the contents of the Alexander's patterns, Gamma's et al. focus on using a pattern format to share best practices. When defining what a pattern is for them, Gamma et al. (1995: 2) quote Alexander's statement made on the second page of 'A Pattern Language'. Alexander writes:

> Each pattern describes a problem which occurs over and over again in our environment, and then describes the core of that solution a million times over, without ever doing it the same way twice. (Alexander et al. 1977: x)

This reference shows what is at the core of Gamma's et al. work, namely the creation of a collection of best practices in software engineering that can be re-used in many contexts. The presented patterns form a collection of best practices, good solutions or concepts that software developers can apply to solve common problems in object-oriented programming. With their collection of patterns, Gamma et al. set out to capture experience from expert programmers and make it available to a greater audience and novice programmers. Its popularity in the software engineering community stands for the success of the approach.

Comparing their approach to Alexander's original work, Gamma et al. note that they do not aim for describing a whole and are not forming a coherent language that supports them in designing an overall system (1995: 356). More than that, the difference is more fundamental. For Alexander, a pattern language is not simply about solving a particular problem, e.g. how an architect should design an entrance, it was about trying to understand what a living, a morally truthful entrance should look like. The aspect of human value, of achieving living environments is missing in the pattern approach taken by software engineering researchers.

Alexander–himself surprised by the sudden popularity of himself in the software community–phrased that profound difference kindly when he was invited to speak at the software engineering conference OOPSLA in 1996. "I don't know whether these features of pattern language have yet been translated into your discipline" (1999), he said and goes on by emphasizing the importance of these missing concepts in the context of his work:

> In the architectural pattern language there is, at root, behind the whole thing, a constant preoccupation with the question, 'Under what circumstances is the environment good?' In architecture that means something.

> It means something important and vital that goes, ultimately, to the nature of human life. (Alexander 1999)

Undoubtedly, transposing the pattern concept has been beneficial for the software engineering community and provided less formal, more practical descriptions of shareable design concepts. Yet, the approach does not share the aspiration to strive for creating living configurations, as envisioned by Alexander.

In the field of HCI, pattern approaches have been applied in the research of human-computer interface design. While there is a closer link between the concepts by Alexander and this work than with the software engineering approach, the targeted qualities are different.

An early reference to Alexander's writings in relation to the design of human-computer interfaces can be found in the 'Macintosh Human Interface Guidelines' of Apple Computer (1992).

> In spite of its practical orientation, the design principles–permeability, variety, legibility, robustness, visual appropriateness, richness and personalization–can be easily transposed to the human interface domain. (Apple 1992: 338)

While Apple Computer suggests that their abstract design principles are a direct result of Alexander's work, they are, indeed, not. Actually, the proposed principles are rather difficult to be linked back to the original writings, leaving open how interaction designers could benefit from Alexander's work. In Alexander's pattern language (1977) there is no notion of criteria on a more abstract level than the patterns themselves. The patterns are Alexander's means to communicate design principles. They generalize instances of design comprising the principles that are otherwise difficult to formulate. Only in his later work, Alexander proposes fifteen properties on a pattern meta level (2002a: 145-235). They, however, are totally different to what Apple Computer suggests.

Later, the HCI research community brought back to their adaptation of Alexander's approach the notion of patterns as a means to capture design principles. Barfield et al. (1994), describe how they incorporate Alexander's work into an interaction design curricula at the Utrecht School of Arts. For

HCI, Barfield et al. understand interactivity as a feature that makes Alexander's approach fit to human-computer interaction.

> Alexander's pattern may even be more applicable to interactive systems than they are to buildings, since interactive systems literally have behaviors inside them. (Barfield et al. 1994: 71)

For their curricula, the authors refer to patterns as their means to capture design principles and let their students discover and reflect them.

As the result from a series of workshops between 1997 and 2001 on HCI conferences, HCI researchers applying Alexander's works, build a more detailed understanding what Alexander's concept of a pattern language could mean for the HCI community (Bayle et al. 1998, Borchers 2000, Borchers et al. 2001, Borchers and Thomas 2001). Borchers et al. (2001) stress the notion of patterns as a means of knowledge sharing and communication not only between experts but also, as Alexander suggested, as a way to include users in the design process.

> The goals of an HCI Pattern language are to share successful HCI design solutions among HCI professionals, and to provide a common language for HCI design to anyone involved in the design, development, evaluation or use of interactive systems. (Borchers et al. 2001)

In a similar manner, Schümmer and Lukosch (2007) construct patterns to support the system design of collaborative, social software and thereby bring the concept to the field of Computer Supported Collaborative Work (CSCW). In their work, the authors refer to Alexander's early work on patterns as well as the later series of the 'Nature of Order'. The pattern language presented, focuses on conceptual system design of certain features in collaborative systems. Mutual awareness, sharing digital objects, and also issues such as session management are themes of patterns that they propose (Schümmer and Lukosch 2007: 51). Despite their broad reference and discussion of Alexander's work, the authors, in their patterns, provide rather technological best practices than a moral guide for developing collaborative systems.

Saffer (2008) takes a less scientific and more pragmatic approach by presenting human-computer interaction design patterns for gestural interfaces. His book collects existing examples in the various emerging computing devices that are not interacted with using mouse and keyboard but by touch or free gestural interactions. In pattern form Saffer presents a number of solutions for optimizing gestural user interfaces.

Critics of such pattern approaches for the design of interactive computing systems point to the immaturity of the field and the constant technological advancement that make it difficult to validate patterns (Borchers and Thomas 2001). Alexander could base his work on patterns on the long tradition of people shaping buildings and towns. He refers to events of human activity at certain places as the foundation of his work of patterns. Transferring this approach to fairly new digital technology patterns of design solutions is therefore difficult. Others ask for a stronger methodological foundation to make the abstraction processes transparent to others that lead to patterns (Borchers and Thomas 2001). Patterns that describe solution for design problems, as presented in computer science, face the difficulty of being chosen and defined without a distinct method and thus appear to be arbitrary, without solid methodological grounding. They are therefore understood as mere rules of thumb, and not as proven knowledge. The approaches taken leave open questions about the rationale behind pattern research in computer science and the quality that validates a pattern.

Looking back at Alexander's work, the question is what a 'Quality Without a Name' means for patterns in computer science. Consequently, some researchers in HCI try to better define how Alexander's timeless quality could be transposed to HCI. Barfield et al. (1994) try to define the 'Quality Without a Name', the 'timeless way of building' for the field of human-computer interaction. For this, they refer to an interview where David Liddle, the CEO of Interval Research Corporation, defined good interaction design.

> [Interaction design] isn't art in the sense that it can be a single person's deep expression. Its value lies in how usable it is and how invisible it is. […] we will know that good interaction design has been done when the tools are nearly invisible, not when the tools seem consciously attractive or consciously pleasant or easy to use but rather when the interaction seems so natural that we're not aware of them at all. (Barfield et al. 1994: 60)

Barfield et al. apply Liddle's concept of invisibility to give the concept of Alexander's living structure, the 'Quality Without a Name' a clearer meaning in the field of HCI.

> Interaction designers can also aim at the quality without a name. When they succeed, their interfaces become 'transparent' and the interaction acquires a natural feel–it becomes a natural element of a user's daily life. (Barfield et al. 1994: 71)

For HCI patterns, the idea is that in human-computer interaction the perceived transparency of the interface could serve as a concept for the 'Quality Without a Name'.

In the following, the human-computer interaction research community builds on this concept. Tidwell (1999) defines a successful human-computer interaction as one where the user is able to understand and to effectively use the presented information and, as the second criterion, asks for the interface to disappear from the user's awareness.

> A successful artifact will 'flow' so well that it lets its users focus entirely upon the task at hand, causing the artifact itself to fade from the user's awareness. (Tidwell 1999)

In his book 'A pattern approach to interaction design' Borchers also calls for transparency in interaction. He directly refers to the work of Barfield, and states: "The term 'transparency' is an approximation of Alexander's 'Quality Without a Name' for human-computer interfaces." (Borchers 2001: 36)

Starting out from this definition of a transparent quality in HCI patterns, researchers aim at using patterns to increase the usability of interactive systems, measuring the efficiency with which a user is able to accomplish tasks with an interface. In this view, interaction specified in a pattern serves as a means to achieve a particular task that can be evaluated by methods of usability research. This pragmatic, usability-oriented approach of using patterns has been adopted for different areas.

Aiming at making interactive applications usable Scott and Neil (2009), for example, present patterns for designing web interfaces and address issues such as editing, drag and drop, selection making, dialogue displays, assistant workflows and search procedures with their patterns. Kunert (2009) presents ten groups of patterns for interactive TV applications. He validates the patterns in a quantitative usability tests.

This interpretation and use of Alexander's patterns and the quality that validates them, is in so far remarkable as it replaces Alexander's living quality for the field of HCI with a quality that is measured using the methods to test the usability in interactive applications. The paradigmatic concept of usability is, however, based on an understanding that the user can be modeled as a more complex machine–following the suggestion by Descartes. According to usability methodology, the human is modeled as an input-output machine, that can be quantitatively measured in order to increase effectiveness and efficiency in human computer interactions (Harrison et al. 2007). The HCI community thereby applies a goal rooted in a scientific understanding of HCI in the spirit of Descartes, to make Alexander's 'Quality Without a Name' graspable to them. This adaptation of the pattern language concept is absurd in so far, as Alexander's presumption was that Descartes understanding of science is too limited to understand the living quality and instead needs to be supplemented by a new holistic criterion that relates closely to humans' experience and intuition. It is therefore rather unlikely that the quality Alexander envisioned, would point to the same results that mechanistic usability methods aim for.

While HCI has made the attempt to transpose the quality in Alexander's work to their field, they failed in preserving the aspect of value that has been at the roots of Alexander's work. There is indeed no reason to suggest that the quality Alexander has described for buildings and towns and the search for living structures does not apply to interactive artifacts. Indeed, Alexander argues for the universality of his approach.

> The quality I have identified [...], the general beyond-biological quality of life as an attribute of all material systems, exists, I believe, to varying degrees in every part of space. It exists, for instance, in the ink and paper of the period at the end of this sentence, and it exists in the ink and paper of the letter q printed here. Of course it exists only very weakly in both, but in a slightly greater degree in the letter q than in the period. (Alexander 2002a: 64)

This critique and comparison with Alexander's work is not to say that these other pattern approaches are wrong or invaluable. Current research shows that pattern languages in HCI are beneficial to practitioners, they are broadly used and useful (Kruschitz and Hitz 2010). There are, however, fundamental differences in the approaches. Pattern languages are not necessarily created to describe living configurations in the understanding that drives this thesis.

Pattern research in the field of HCI that is focused on understanding users and inspiring design through ethnography, provides examples of 'activity patterns' that strive for the same quality that Alexander describes.

Instead of adapting patterns as a useful format to describe design solutions, a second approach to make use of Alexander's pattern concepts in HCI builds on the idea that patterns are a means to understand human activity. As a result of a workshop on patterns supporting interaction design, Bayle et al. (1998) argue for a continuum of patterns from 'design patterns' that layout sometimes very specific design solutions to 'activity patterns' that describe the environment. These activity patterns make use of the idea that the quality of life also "exists in varying degrees in different human events" (Alexander 2002a: 64)

In the same spirit, Erickson (2000a, 2000b) suggests pattern languages as a 'Lingua Franca' for people coming from different disciplines, for all stakeholders in the interactive design process. He addresses the interdisciplinary nature of interaction design and the need to design systems that integrate well in existing workplaces. Erickson proposes pattern languages to make available ethnography for design. He understands Alexander's pattern language as a means of communication at the border of ethnography and design. Following the spirit of Alexander's pattern language, Erickson is grounded in the social configuration and is concerned about the values in the context of use. By the example of Hester (1993), Erickson argues that pattern languages can help to build bridges between users and technology designers and that such pattern languages, tailored to local needs, therefore can make a valuable contribution to design problems. He calls for those site-specific pattern languages to be used when designing specific solutions. For him, the site-specific languages serve as an intermediated step to achieve a more general lingua franca in the long term. As an example, Erickson makes use of a report on collaborative work practices in a distributed design consulting firm by Bellotti and Bly (1996) to propose patterns that describe how the design consultancy works and could be used when designing computing systems for such company. Specifically, the patterns proposed by Erickson (2000a: 364) deal with the social interactions among people and describe individual habits and should inform the design process in a qualitative way.

> The point here is not that these patterns and their relationships should be used to reject or approve changes, but rather that they 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. (Erickson 2000a: 366)

Erickson's work is thereby very close to the original concepts of Alexander–especially when compared to the pattern research in computer science previously described. Erickson describes environments that are good and he cares for the whole. He also provides a pragmatic description of the 'Quality Without a Name' that does not limit its meaning. This quality is simply "a shorthand for systems which really 'work' for people in all of the many meanings of that phrase." (Erickson 2000a: 361)

Inspired by Erickson's approach, Martin et al. (2002) work on finding patterns from ethnographic studies of cooperative interaction in governmental work environments. By the example of their pattern 'Working with Interruptions' Martin et al. show, how such pattern could be used to form a number of design implications. Pattern serves as a means to present empirical findings and inform design processes. In the work of Martin et al., however, the notion of linked patterns that form a language to describe a working system as a whole, as envisioned by Erickson, gets lost.

A similar approach can be found in the work of Crabtree et al. (2002) who present patterns to support the design of future computing technologies for the home. Crabtree et al. motivate their pattern approach by the nature of the home setting, where standard measurements, originally developed for office environments, do not, or only partly, apply and yet ethnography should inspire future designs. By using video ethnography and thick descriptions (Geertz 1973) of the activities, the authors film people's activities in their homes and identify emerging patterns. Patterns of social action are a means "for structuring and presenting ethnographic fieldwork" (Crabtree et al. 2002: 265). In their work, the authors provide an exemplary pattern that describes the activity center of the kitchen table as an artifact that forms a design space for future technologies. Crabtree et al. closely relate their work to the original writings by Alexander. They extend Alexander's understanding of patterns to computing technologies and hypothesize that patterns of technology use in the home "make unsupported use practices available to the design of future technological arrangements in place." (Crabtree et al. 2002: 269) In this way, patterns become a tool for value-sensitive inventions.

McCullough (2005), whose interest is at the intersection of architecture and ubiquitous computing, also proposes patterns of human behavior in his work towards a typology of situated interactions. He points to the dynamic character of patterns in the face of ubiquitous computing. He argues that "[r]epeating relationships embody workable conventions. These are not rigid rules, but transformable configurations." (2005: 55) Also, he adds that a pattern framework does not restrict the design in a negative way. Instead, patterns inspire design, a pattern language "recognizes how creativity does better with themes and variations." (2005: 118)

In summary, pattern languages of human activity support the creation of living configurations.

As the previous research shows, pattern languages of human activity have been used as a tool in the interaction between the design of computing artifacts and the understanding of a context-of-use. Applied in this way, they allow preserving Alexander's perspective of answering the question of a working, a good social configuration.

3 Methodology

Grounded theory, as a qualitative method to identify patterns in empirical data, and action research, as a methodological concept that allows studying the interaction between new technologies and existing practice, solidify the methodology of pattern research.

3.1 Alexander's Methods

Alexander suggests creating patterns by identifying places that are alive through human intuition, careful observation and thought.

As previously stated, the methodology for the formation of patterns has been questioned, both in the HCI and architectural community (Borchers and Thomas 2001, Saunders 2002). And even though there are calls for using patterns and pattern languages as a means to present the results of ethnographic studies (Crabtree et al. 2002, Erickson 2000a, McCullough 2005), little has been said about the methods to follow that lead to patterns and a pattern language. To define the methodology for this research, this chapter therefore takes a deeper look at the original methods proposed by Alexander and puts it in context to related methodological works.

Alexander's motivation is the creation of shareable descriptions of real-world contexts. To achieve that objective he uses a number of methods.

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

First, his method starts with observation that relies on empathy with the users.

The process of pattern discovery itself, takes time and "must always start with observation." (1979: 254) This observation is a personal and situated activity. Alexander 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. (1979: 249)

To produce a pattern, one needs to answer three questions that form the inner structure of a pattern:

> What, exactly, is this something? Why, exactly, is this something helping to make a place alive? And when, or where, exactly, will this pattern work? (1979: 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?' thus inserting yourself into the situation, and then using your own common sense and feelings as a measuring instrument. (2002b: 352)

Second, comparisons with negative or positive examples help to identify a working configuration and the patterns in it.

Alexander compares specific configurations to others, 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 (1979: 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? Which of the two induces a greater harmony in me, in my body and in my mind? Which of the two makes me feel a greater wholesomeness in myself? (2002a: 355)

The answers support Alexander in looking for similarities in the positive examples.

Third, patterns are also based on positive past experiences and the imagination of users.

Alexander works with the experience of users and their imagination. He directly asks people for the places of their dreams (2002b: 355, 2004: 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: 355)

He follows the same approach in building the campus at the university of Eishin, Japan where he asks students and teacher for an imaginary perfect place to study and teach.

> [O]ne of the things I remember several people said in one form or another, "I would like to be able to take a walk along some little stream or some little pool while I am thinking about my next lecture [...]" In time, this need for water was incorporated in the pattern language; and then put into the plan, in the lake we built. [...] Now, years later, the campus is built, and has been used for years. The water, dreamed of by those teachers long ago, is actually in the school in form of that lake. (Alexander 2004: 250)

Fourth, another means to study working configurations is to create prototypes and test their impact by forming a shared vision with the users.

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 existing configurations. To do so, he actively changes the environment. Based on the understanding that for each problem, the interaction between the designed solution and the surrounding context is unique; patterns need to be iteratively tested. Alexander gradually tries to understand the relevant forces in a given context and takes an incremental approach to design. Using prototypes, he continually checks back which feelings a design evokes in-situ.

He incrementally tries to understand the relevant forces in a given context using prototypes by continually monitoring the feelings that a prototype evokes in-situ. With paper he simulates beds and checks sleeping positions in a house (Alexander 2002b: 611). For a bench in at the bay cost of San Francisco, California, Alexander and his students, for example, built a mock-up, a paper prototype of the bench to experience it in its context (Alexander 2005: 355). In another case, paper prototypes of a column help to define its shape (Alexander 2004: 126). Alexander highlights the process of design as collaboration among the stakeholders. During the process people build a collective vision of the future design. Such shared vision is a vital need (Alexander 2005: 257ff).

Fifth, the configuration should be described in contradicting forces that the pattern solves. The patterns should describe very concrete details of a specific configurations.

Once identified, Alexander suggests describing problems as a system of contradicting forces that the pattern helps to resolve. The specific description of the problem that a pattern resolves allows to justify the need for a pattern and to detail the goodness or living quality of a pattern.

The pattern 'Alcoves' (1977: 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 in respect of other household members and the force of household members to be together while following their individual activities. These contradicting forces are resolved by the 'Alcoves' pattern.

For patterns, Alexander asks for a description of features that are directly usable and transferable to other applications. In his example, a room of a house should not be described with the abstract property of being cozy or spacious. Instead of providing such pure replication of the feeling that the space invoked, Alexander asks for a specification of features of that particular room that are causal to the impressions and feelings and are concrete enough, so that the pattern can be used as a formative guideline when designing other buildings. In the example above, Alexander suggests the description of alcoves in the room with seating places as a pattern that fulfills the requirement of being well defined (Alexander 1979: 250-251). The above-mentioned pattern 'Alcoves' proposes a construction guideline.

> Make small places at the edge of any common room, usually no more than 6 feet wide and 3 to 6 feet deep and possibly much smaller. These alcoves should be large enough for two people to sit, chat, or play and sometimes enough to contain a desk or table. (Alexander et al. 1977: 832)

Sixth, patterns need to be put in a context where they apply. The context can be provided by linking to other patterns, a pattern language results.

A pattern only works in a specific context and in addition to the specific solution, the context of the pattern therefore needs to be described. The context can be specified as a configuration of related patterns. The 'Alcove' pattern, for example, only apply for households with multiple members. Other, related patterns allow defining the context of a pattern and put it into the frame of a pattern language.

For the context of studying firefighters' frontline practice, the application of Alexander's methods is not straightforward. A comparison with other, scientifically acknowledged approaches should help to make the methodology sound.

Transferring the proposed methods from the context of architecture to the context of ubiquitous computing solutions is not straightforward, as the visual approach and the intuition of assessing wholes that stems from the 'being in space', is difficult to achieve for distributed and dynamic contexts that are yet to be changed by human design. The configuration 'firefighting' is highly distributed; its complexity is impossible to be captured in static visual form. Additionally, comparisons and questions are less obvious to make and cannot rely on past experiences of the users since this work intends to inform the design of technology that does not exist yet.

With the pattern work of Alexander in mind, I therefore, in the following, borrow from the methodological frameworks of grounded theory and action research that help to adapt Alexander's concept for the context of firefighters and future ubiquitous computing systems.

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.

3.2 A Pattern Language as a Grounded Theory

The pattern language emerges as a theory, a set of hypothesis or model that tries to explain a certain quality inherent in spatial configurations and human activity; it therefore can be understood as a grounded theory.

Abstractly, Alexander's creation of a pattern language can be framed as instance of research, where an initial interest or issue, such as the quality of life in building structure, is explored in a bottom-up process by means of empirical studies.

From this perspective, Alexander's work appears similar to the methodological considerations by Glaser and Strauss, two sociologists, who, not far from Alexander in Berkeley, developed the grounded theory method at the University of California, San Francisco.

Grounded theory has its roots in a study from another field. Glaser and Strauss were studying the social aspects of dying and death in hospitals. Their book, entitled 'Awareness of Dying' (Glaser and Strauss 1965) presents findings from studies in different hospitals focused on the process of dying and how nurses, doctors, family and the patients handle these situations. Glaser and Strauss show that there are different patterns in the interaction between the actors that range from closed awareness–for which the people involved try to hide the imminent death–to open awareness–for which staff and relatives engage in an open communication process while accompanying the patient on his way to death. In great detail and with considerations for various complexities and relations, Glaser and Strauss derive a theory from the empirical data that they suggest to be useful for hospital staff as a means for reflection on their work as well as a scientific contribution the sociological community. The book remarks the beginning of a methodological endeavor of how theories can be created in a scientific manner. Even though their focus in 'Awareness of Dying' was on the contents of the theory, Glaser and Strauss provide an initial description of the grounded theory research methodology that shows the broadness of the approach.

> The reader who is unacquainted with this style of field research need only imagine the sociologist moving rather freely within each medical service,

> having announced his intention of 'studying terminal patients and what happens around them' to the personnel. The sociologist trails personnel around the service, watching them at work, sometimes questioning them about its details. He sits at the nursing station. He listens to conversations himself. Occasionally he queries the staff members, either about events he has seen or events someone has told him about. Sometime he interviews personnel at considerable length, announcing 'an interview,' perhaps even using a tape recorder. He sits on staff meetings. He follows, day by day, the progress of certain patients and conversation about the patients among the personnel. He talks with patients, telling them only that he is 'studying the hospital.' His fieldwork takes place during day, evening and night, and may last from ten minutes to many hours. (Glaser and Strauss 1965: viii-ix)

After defining their perspective, Glaser and Strauss look for patterns in the data. The theoretical scheme that arose from the data is 'awareness contexts' and describes who of the involved people is having what information about the death process. The scheme helps to form patterns that make up the theory that should help to understand the situation.

> The efficiency of the theme allows us to claim–we believe with some persuasiveness–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. (Glaser and Strauss 1965: ix)

Concluding their theory in 'Awareness of Dying', Glaser and Strauss (1965: 259-273) reflect on the use of and generality of the theory that they formed and discuss the methodology also in relation to the authors backgrounds, the role of analyzing data in different comparison groups, and the need for further discussion and validation of such kind of grounded theory (Glaser and Strauss 1965: 286-293).

Grounded theory is a well-defined methodological approach.

The thorough discussion of the approach is provided in their seminal work 'The Discovery of Grounded Theory: Strategies for Qualitative Research'. In it, Glaser and Strauss (1967) suggest their methodological approach for creating scientific theories as an alternative to research focused on hypothesis testing. Research focused on hypothesis testing, on the evaluation and verification of exiting theory, does not necessarily consider the local needs and therefore might not be able to fulfill the needs of the situation at hand. Choosing a theory before approaching the field, the researcher arrives on-site with a hypothesis that she puts to a test. In such approaches, the research does not necessarily fit and work with the context of study; the relevance of the research for the context is not a criterion of evaluation. Glaser and Strauss aim at creating theories that fit and work well in their respective contexts. In grounded theory, the lens of research is not defined a priori; instead, it evolves in the course of the study, grounded in the phenomenon at hand. The iterative process that is solely based on empirical data and open towards the outcome holds a greater potential to be not solely meaningful for the purpose of research but also to be useful in the context in which the research is conducted. Following grounded theory, an inductively derived theory ensures that resulting knowledge fits and works within a given context. Glaser and Strauss define the fit and work as follows:

> By 'fit' we mean that the categories must be readily (not forcibly) applicable to and indicated by the data under study; by 'work' we mean that they must be meaningfully relevant to and be able to explain the behavior under study. (Glaser and Strauss 1967: 3)

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

The overall theory is a result of the integration of the individual elements and provides the final framework. Glaser and Strauss distinguish between two kinds of theories that can be created and suggest a two-step process. Initially, a substantive theory can be formed that is useful within and developed for a more specific context. Based on that work, a formal theory can be formed that follows to more abstract concepts and can therefore be use in a broader context (Glaser and Strauss 1967: 32) or apply to multiple areas (Glaser and Strauss 1967: 82). Not all research on grounded theories, however, has to go both steps.

Practically, the grounded theory method can be summarized as follows. In a number of iterations, the researcher collects empirical data, 'theoretical sampling' as Glaser and Strauss (1967: 45) coined the process. Theoretical sampling feeds the research and helps to iteratively saturate the theory. Following the theoretical sampling process, the researcher selects different data groups for her research. The choices of groups are made as the theory emerges; there is no fixed, pre-defined plan. Differences between the groups might include the type of data and range, for instance from interviews to the analysis of work documents. Also, those differences might be either small to study subtle differences and bring more evidence to existing categories, or the differences can be large to understand fundamental differences or understanding the scope of the theory. Here, the goal is not to sample all possible cases but instead to define a path that supports the creation of the theory. Important is foremost how sound and useful the developed theory is. For the formation of the theory the evidence can be limited in comparison to methodological approach focused on verification of existing theory. Or, as Glaser and Strauss put it:

> Since accurate evidence is not so crucial for generating theory, the kind of evidence, as well as the number of cases, is also not so crucial. A single case can indicate a general conceptual category or property; a few more cases can confirm the indication. (Glaser and Strauss 1967: 30)

Instead of aiming at the largest amount of evidence, the central task is to "develop a theory that accounts for much of the relevant behavior" (Glaser and Strauss 1967: 30) that fits the practice and works.

The data resulting from theoretical sampling is first coded and the analyzed using the 'constant comparative method', a way for qualitative research analysis based on comparison of wide-spread data (1967: 101). Properties and categories start to emerge.

To code data, Strauss and Corbin (1990: 77) suggest asking questions about the "Who? When? Where? What? How? How much? and Why?" of the data. Such questions should help the researcher as a starting point for more specific follow-up questions that aim at building categories and their properties. Individual findings are then compared to each other.

Glaser and Strauss (1967: 22-31) provide a number of uses how comparative analysis supports the grounded theory methodology in its analysis of empirical data. First, the comparison of findings serves as a means to prove evidence of categories found. For grounded theory, such comparative evidence does not necessarily need to exist in the beginning and instead might develop over time, as initial findings might serve as a hint for categories that yet need to be discovered in future investigations. Second, comparing results helps to understand the level of generalization of a particular finding. By comparing findings to different contexts, the researcher might find that the category developed applies to a higher level of greater generalization beyond the local context. Third, comparison might be useful to highlight the specifics of a certain concept by means of the findings that are unique to the field of study and help to differentiate it from other contexts. And fourth, comparative analysis is a tool for verifying the emerging theory. Yet, as Glaser and Strauss note, the verification of theory should not distract the researcher from his principal task in the grounded theory approach, namely to create a theory that fits and works within the context of study. For those reasons, the comparative analysis is used as the analytical tool in grounded theory methodology.

The process of the constant comparative method is described by Glaser and Strauss as a four step process (1967: 105–113).

In step one, 'comparing incidents applicable to each category', the researcher identifies incidents in the data, compares them and builds categories. For each incident the source should be referenced to that that the data can be traced back to its data group. Over the course of the research the categories will increase their abstractness. Glaser and Strauss describe the quality of this coding process, its rhythm and speed as highly variable, in relation to the empirical data at hand (1967: 107).

In step two, 'integrating categories and their properties', the focus shifts from the comparison of incident to incident to the comparison of incidents found in the data with the already existing categories and properties. Thereby, the analysis can become more specific and also allow detecting new questions that can be answered through new input from theoretical sampling.

In step three, 'delimiting the theory', the researcher aims at increasing the integrity of the theory. The step includes the reduction of theory elements towards more abstract concepts. This also allows to generalize the theory and to better define its scope. In this phase, the theory theoretically saturates. Most of the findings can be related to existing categories. The saturated grounded theory is however not closed; it instead also gracefully can be extended with novel categories.

Finally, in step four, 'writing theory', the researcher, convinced of the saturation of the theoretical framework, writes up the theory.

The comparative analysis should be performed in parallel to the coding of the data. Glaser and Strauss (1967: 101–102) suggest intertwining the coding and the analysis process so that, on one hand, the theory gains credibility and rigor through being tightly linked to the empirical data and, on the other, the process is at the same time open enough to allow novel concepts to emerge organically. Only after its completion, the grounded theory is discussed in relation to existing theories and extends, confirms or rejects them.

This method, while stricter and better defined than Alexander's approach, cannot be applied mechanically; it greatly relies on the skills of the researcher and requires theoretical sensitivity.

Strauss and Corbin (1990: 26) call for 'theoretical sensitivity', as a personal quality of the researcher required to analyze empirical data in order to improve the credibility of the results in addition to methodological soundness. They argue that the analytical perspective and outcomes of a grounded theory approach are not independent of the person who is conducting the research, the profession and prior knowledge, simply from being in the world, is a factor that has to be considered and reflected upon.

> Theoretical sensitivity refers to a personal quality of the researcher. It indicates an awareness of the subtleties of meaning of data. (Strauss and Corbin 1990: 41)

The sensitivity can be achieved through both professional and personal experience. Strauss and Corbin (1990: 42–43) give the example of a nurse who can benefit from her professional experience, were she to create a grounded theory on nursing in hospitals and the example of the researcher's own experience of a divorce that can make him sensitive to the concept of loss. Such experience can be related to the current field of research or to the methodology. Nevertheless, while such experience is source for developing theoretical sensitivity, the experience can also hinder the grounded theory process when professional experience blinds the researcher from detecting routines and when personal experience is overwriting empirical findings.

According to Strauss and Corbin, the sensitivity can also be gained through reading. In a more extended view on the use of literature and in contrast to what Glaser and Strauss (1967: 37) said before, Strauss and Corbin (1990: 51) suggest the reading of literature that provides descriptive accounts of the field. This literature review can help the researcher to become more sensitive with his data at hand, yet should not make the research to simply adapt categories found in other work to their own data. Additionally, philosophical writings and other existing theory can be used to define the research focus. Generally, the grounded nature of the theory needs to be preserved. The discovery of categories is the central goal. The researcher has to reflect on her level of theoretical sensitivity, to reflect on previous knowledge and the ongoing work and to follow the methodology to insure the validity of her research. Credibility of the results is achieved through sound arguments and the contents of the theory itself. To support the credibility of his theory the researcher …

> can quote directly from interview or conversations that he has overheard. He can include dramatic segments of his on-the-spot field notes. He can quote telling phrases dropped by informants. He can summarize events or personas by constructing readable case studies. He can try his hand at describing events and acts; and often he will give at least background descriptions of places and spaces. Sometimes he will even offer accounts of personal experience to show how events impinged upon himself. Sometimes he will unroll a narrative. (Glaser and Strauss 1967: 229)

In contrast to Strauss and Corbin (1990) who critically reflected on making the methodology more sound, Glaser (1998: 17), in his later work, argues for credibility through the quality of the results. "[T]he proof is the outcome", he notes, and proposes questions about the fitness and ability to explain phenomena of the theory, its relevance for the people in the field and its flexibility for being modified when new data emerges, as a means to evaluate the quality of the outcome.

The motivation, approach and architecture of grounded theory are similar to Alexander's pattern language and therefore should become the methodological guide in creating patterns.

Comparing grounded theory with Alexander's pattern language reveals the parallels of the approaches (Figure 5).

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. For pattern research and grounded theory there is the need to create a theory from a social context.

Both methods derive patterns by comparing phenomena. While grounded theory does exclude to work with negative examples, the flip-flop technique suggests to consider the extreme opposite of a particular issue as a means for comparison (Strauss and Corbin 1990: 84).

The structures of the resulting theories also compare. Patterns emerge from observation and categorization of human behavior, as do the categories in grounded theory. For both approaches links between the patterns, hypothesis 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.

Consequently, one can argue that Alexander's pattern language can be understood as a grounded theory of the living quality of towns and buildings. Alexander's theme, his core category, is the quality without a name. His theory relies on a variety of empirical sources. And, as the commercial success of his publication shows, he succeeded in creating a theory that is relevant to various home builders (Saunders 2002: 1).

Grounded theory, however, does not include the overall motivation of design and the idea that changes in the practice by prototypical artifacts can be used to improve understanding. Here, the concept of action research (Lewin 1946) that is presented in the following, provides a theoretical framework.

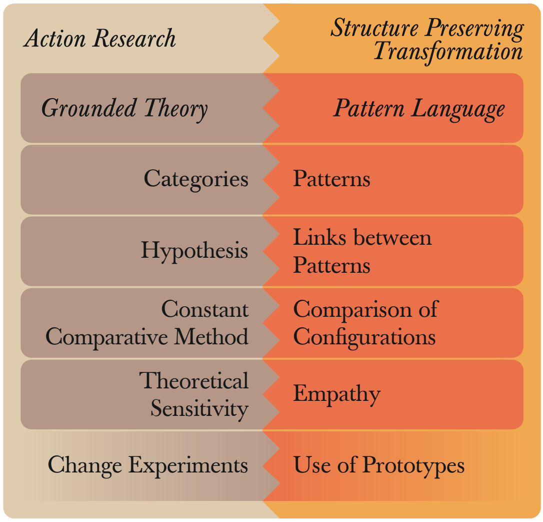

Figure 5: Action research and grounded theory can be transposed to Alexander's concepts of structure preserving transformations and pattern languages

3.3 Adding Action Research

The pattern language learns from changes produced through early prototypes. This approach of changing the environment at hand and learning from the resulting effects can be found in action research methodology.

Action research is a methodology that builds on the understanding that complex social processes can be studied best by actively introducing changes into existing practice and by learning about the social system from the effects that such changes cause. This approach allows to study a social setting as a whole and to learn about the complex interactions and dependencies that it comprises.

As discussed earlier, Alexander, especially in his later work, makes use of prototypes to inform the creation of pattern languages. From the experience that results from introducing prototypes, he refines designs and tests hypotheses. This process can be understood as an instance of action research.

Action research has been applied in diverse ways that share the common concept that change produces understanding and that systems should not be fragmented for study.

The term action research can be traced back to the work of Lewin (1946) who was faced with the task to answer complex questions of the social discrimination and other factors of intergroup work relation of minorities in the U.S. state of Connecticut. He saw that due to the social complexity, standard analytic means of research alone produced superficial results. Important questions of the local situation remained unanswered and therefore the results of social sciences had little effect for the situation at hand. For such complex social issues "research that produces nothing but books will not suffice." (Lewin 1946: 35) Hence, Lewin (1946: 35) called for action research, as "a comparative research on the conditions and effects of various forms of social action, and research leading to action." In action research, the researcher becomes part of an interdisciplinary team that initiates changes and iteratively learns about the local system from the changes that these changes cause. Action research is introduced by Lewin motivated by giving research meaning and actually support advancement for the problematic situation at hand and by the complexity of the local situation that cannot be grasped with solely analytic approaches.

In 1985, Wood-Harper applied action research in the field of computer science; first, as a means to compare different methodologies, then as a means to better capture the users' needs. Driven by the methodological question of how to design computerized information systems, Wood-Harper initially tested the applicability of different methodological approaches for information systems research by using an action research approach (1985). In 'Multiview Approach' (Wood-Harper et al. 1985) the authors present a methodology for designing information systems that takes into account existing organizational structures and thereby tries to better match the users' needs. Wood-Harper et al. suggest action research when faced with great complexities in specifying information systems and user needs. Specifically, they mention the use of prototypes as a means to learn about the inner workings of a socio-technical overall system.

> Many situations will emerge in the trial of the prototype that no one had thought about in the verbal specification. Sometimes, even when it is

known that there is a situation, which causes design difficulties, a solution cannot be found in advance. Computer systems are not very adaptable, and therefore it is necessary to make these decisions so that they are built into the system. Until the day when computer systems are sufficiently flexible that they will respond to unusual situations on the basis of accumulated experience, in the way that human operators would, acting out a situation is the best way of making decisions. (Wood-Harper et al. 1985: 121-122)

As Baskerville and Wood-Harper (1998) show more recently, action research methodology in the area of information systems has been applied in great number of forms. The process model can vary from iterative to linear, structures are more rigorous, such as the canonical action research described by Susman and Evered (1978), or more fluid, such as in the work by Jepsen et al. (1989). In these approaches, the role of the researcher and interaction with the participants varies as well as the primary goals of the research. Despite this variety, action researchers share the assumption "that complex social systems cannot be reduced for meaningful study" (Baskerville 1999: Part II). In the context of research on the design of information technologies, this means that …

human organizations, as a context that interacts with information technologies, can only be understood as whole entities. (Baskerville 1999: Part II)

Splitting the problems of social-technical issues into pieces and studying them individually, does not generate knowledge about the configuration as a whole.

This foundation in the methodological approach of action research is notably similar with Alexander's critique of the mechanistic understanding of the world that confuses the scientific, methodological approach of Descartes to build up an understanding of the parts in order to understand the whole with the real, interrelated structure of nature. To be able to study system as wholes, action research proposes that …

complex social processes can be studied best by introducing changes into these processes and observing the effects of these changes. (Baskerville 1999: Part II).

This understanding is in direct opposition to the positivist concept that the researcher should retain a neutral, outside perspective in order to produce objective results. Action research argues that such objectivist perspective is impossible to achieve, as the researcher himself always is subject of numerous influences that he cannot free himself of. The researcher takes an interpretivist viewpoint (Baskerville 1999: Part II), who understands all knowledge as a matter of subjective interpretation. In action research there is no need to stay outside or neutral and the researcher actively produces changes in the system. Such changes or actions produce results that are the basis for the creation of knowledge. The researcher, who affects the object through change, becomes part of the study. Hence, knowledge is created through subjective interpretation. As this might appear to make knowledge creation completely personal or even arbitrary, action research asks the researcher to reflect on her own background, values, knowledge, her Weltanschauung (world-view) and to disclose those influencing factors as much as possible. As a result of that thinking, solving the problem at hand becomes the primary goal of action research.

Checkland argues that the complexity of the 'human activity system' makes it impossible to describe or model it in a single account. In action research, the concept of general conceptualization is replaced by local design (Checkland 1981: 191). Or, put differently, "action research aims for an understanding of a complex human process rather than prescribing a universal social law." (Baskerville 1999: Part III) This focus on the local needs, nevertheless, does not exclude action research from developing theory. Especially for its focus on situational needs action research "is a fine theory discovery method." (Baskerville and Wood-Harper 1996: 241) Problems of action research about unaccepted or weak outcomes are not a result of the research itself but are rather caused by lacking rigor in the execution of the methodology or by a judgment of the results with a non-matching scientific paradigm. Theory developed through action research can, when published in the larger scope of the research community, make meaningful contributions to the creation of scientific knowledge (Baskerville and Wood-Harper 1996: 240).

Action research and grounded theory have been shown to be complimentary. This research adds action research by introducing technological artifacts to the practice and learns about the configuration from the resulting effects.

With regards to the relation of action research and grounded theory, Baskerville and Pries-Heje (1999) propose that certain methods from grounded theory such as open coding and the formation of categories and core categories can bring the required rigor and methodological soundness to action research approaches. Grounded theory methods, injected into action research throughout the cycle, can especially help to support and improve the specification of learning at the end of each cycle. Accordingly, Alexander's overall design approach can be understood as an instance of action research, given his focus on the overall configuration, in which the pattern language concept serves as a grounded theory that also gains samples by action research experiments (Figure 5).

In consequence for this research, action research is introduced as a means to produce novel input, new data to be sampled using grounded theory. Instead of following a canonical form of action research, the work is guided by the understanding that change is a means to understand about an existing configuration. Action research experiments will be guided by and become part of the theoretical sampling and coding process towards the pattern language as a grounded theory.

Both action research and grounded theory have been applied in the field of HCI.

While originally stemming from other fields, the two approaches have been transposed to the field of HCI, supporting developers in understanding socio-technical configurations. While there is a wide body of work that could be cited in this context, some provide methodological approaches that are especially relevant for support the work with pattern languages.

Following the ideas of action research, HCI introduces approaches such as triggering artifacts (Mogensen and Robinson 1995) or experience prototypes (Buchenau and Suri 2000). In both cases, technological artifacts are introduced in the practice not as a prototype of a later product or to test a previously defined hypothesis, but as a means to change the existing practice and to learn from the resulting effects about users or, more broadly, about the original configuration. Also following action research, Scandinavian HCI researchers propose design processes in which users cooperate with designers and have their say, they become empowered actors in a participatory design processes (Bjerknes et al. 1987).

For grounded theory in HCI, contextual inquiry methodology provides an instance and practitioner-oriented description of how to produce a grounded theory for informing design processes. Holzblatt et al. (2004) use the contextual inquiry method to inform the processes of interactive systems design by data gathered in the context of use. The transcripts of workshops and interviews are walked through thoroughly, avoiding summarizing or skipping data. As a result of this analysis, so called 'affinity notes' are created to capture a variety of insights from the analysis such as interpretations of events, the use of artifacts in practice, existing problems and technological opportunities, characteristics of the work, breakdown situations during the interventions and in interaction with technological artifacts, cultural influences and insightful quotes (Holtzblatt et al. 2004: 115). Grouping of affinity notes in 'affinity diagrams' (Holtzblatt et al. 2004: 159) makes visible commonalities and relations in the diagram.

In order to develop theoretical sensitivity, HCI researchers have introduced 'empathic design' as a method to develop empathy with the users but at the same time, to retain the professional outside perspective. Empathic design also has become a means to spark innovative solutions by combining the perspectives from designers and practitioners (Leonard and Rayport 1997, Mattelmäki and Battarbee 2002, Wright and McCarthy 2008).

This thesis comprises data from ethnographic studies, empathic exercises and the introduction of novel ubiquitous computing systems to be analyzed, following the constant comparative method.

Following the methodological approach outlined in the previous sections, my research comprises three kinds of studies.

First, ethnographic studies analyze current firefighting practice by means of observation, interviews and document analysis to provide a broad account of knowledge about the context on the frontline.

Second, empathic exercises build up personal experience of frontline firefighting to increase theoretical sensitivity and to develop empathy.

And third, studies introduce novel ubiquitous computing artifacts into existing practice, as experiments that actively, in close collaboration with the users, seek to produce changes and to understand the dynamics of existing practice and its reaction to outside triggers.

All the resulting materials are analyzed, following the constant comparative method and making use of affinity notes and diagrams to group the data. Alexander's vision of working configurations provides the overall theoretical lens.

4 Field Studies

Workshops with firefighters at professional training facilities produce empirical data. Workshops comprise the observation of existing practice, the active participation in firefighting exercises, the introduction of novel artifacts and other design-oriented activities.

4.1 Overview

Data coming from a range of multi-sited, bi-national user studies forms the empirical base. Over a period of three years, a variety of workshops with firefighters were organized ranging from interview sessions at a fire station to simulated interventions at firefighting training facilities.

This research was conducted, for the greatest part, in collaboration with two firefighting organizations. In the beginning, workshops took place at the training center and fire station in St. Denis with firefighters of Paris. Later, workshops were conducted with the firefighters of Cologne, Germany. The workshops in Germany took place at Europe's most advanced firefighting training facility, the State Fire Service Institute of North-Rhine-Westphalia in Münster, Germany, that allows to simulate interventions close to real world conditions and at the Firefighters' local fire station that features a breathing fitness parcours and a heat training facility. 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–a setting that drew a close connection between real-world incidents and what was discussed in the workshops. Besides studies conducted solely for the purpose of this particular research, other activities with the Cologne firefighters and teachers of the State Fire Service Institute were more design-oriented and part of a larger research project that aims at building a navigation support system for firefighters working on the frontline.

In combination, both firefighting organizations provide a diverse picture of firefighting practice. While the Parisian firefighters are a military division, the Cologne firefighters are an entirely civil organization. Also, procedures and tactics vary, as do the tools in use.

Adding to the work with these two firefighting organizations, work place observations and interviews were conducted with three firefighting crews operating in special contexts. The first study took place at a large chemical plant that has its own permanent crew of firefighters who are experts in dealing with chemical threats and are, for this expertise and their special tools, also called by public service firefighters when needed. The second study was with the firefighters of Bremerhaven and included a trip to the container port terminal and the facilities for the decontamination when dealing with leaking dangerous good containers. The third study involved the firefighter of the city of Bonn, observing an exercise in the city's subway system.

Grouped into the section of ethnographic studies that aim to understand firefighting from an observer's perspective, empathic exercises that focused on hands-on experience of firefighting practice, triggering artifacts that introduced new technology to existing practice, and activities focused on designing ubiquitous computing support in close collaboration with firefighters, the following list provides an overview of the studies conducted.

Ethnographic Studies

Location	Duration	Description
St. Denis, France, training center, firefighters of Paris	1 day	Simulated search and rescue mission, reference missions.
Münster, Germany, Fire State Service Institute, Managers and Teachers	1 day	Introduction to the training methods and facilities, planning future workshops.
Cologne, Germany, Fire Station 6, Firefighters of Cologne	½ days	Presentation of existing at the station tools.
Münster, Germany, Fire State Service Institute, Firefighters of Cologne	½ days	Interviews with a brigade on existing tools.
Leverkusen, Germany, Bayer Chemical Plan, Bayer Firefighters	½ days	Introduction to the work of firefighters at a chemical plant.
Bremerhaven, Germany, Firefighters of Bremerhaven	1 day	Introduction to the work of firefighters at a container port.
Bonn, Germany, Firefighters of the City of Bonn	½ days	Participation in firefighters subway inspection exercise.

Empathic Exercises

Location	Duration	Description
St. Denis, France, training center, firefighters of Paris	1 day	Participation in firefighting training.
Münster, Germany, Fire State Service Institute, Firefighters of Cologne	½ days	Role-playing workshop of an entire intervention as commander.
Münster, Germany, Fire State Service Institute, Firefighters of Cologne	½ days	Role-playing workshop of an entire intervention as frontline firefighter.
Cologne, Germany, Fire Station 6, Firefighters of Cologne	1 day	Heat exercises with real fire and breathing fitness training
Cologne, Germany, Fire Station 6, Firefighters of Cologne	½ days	Entering the heat training facility again.

Triggering Artifacts

Location	Duration	Description
St. Denis, France, training center, firefighters of Paris	1 day	Simulated search and rescue mission adding a digital command post system.
Münster, Germany, Fire State Service Institute, Firefighters of Cologne	1 day	Test of commercial egress transmitter system.
Münster, Germany, Fire State Service Institute, Firefighters of Cologne	½ days	Participation in workshop introducing a military training command system to firefighters.
Cologne, Germany, Fire Station 6, Firefighters of Cologne	½ days	Interviews on interactive jackets.

Design-Oriented Activities

Location	Duration	Description
Cologne, Germany, Firefighter Headquarters, Firefighters of Cologne	½ days	Discussion on navigation support systems and future collaboration
Münster, Germany, Fire State Service Institute, Firefighters of Cologne	1 day	Discussions on ubiquitous computing navigation support with firefighters and project partners.
Sankt Augustin, Germany, Fraunhofer FIT	1 day	Participatory design workshop on computing support with firefighters and project partners.
Lübeck, Germany, Workshop at Dräger with project partners	1 day	Workshop on licensing firefighting equipment the testing required by commercial firefighting products.
Karlsruhe, Germany, Technical University	1 day	Participatory design workshop on ubiquitous computing navigation support with firefighters and project partners.
Münster, Germany, Fire State Service Institute, Firefighters of Cologne	½ days	Initial tests of in-mask feedback.
Münster, Germany, Fire State Service Institute, Firefighters of Cologne	1 day	Test of mobile device and in-mask beacon interaction.
Münster, Germany, Fire State Service Institute, Firefighters of Cologne	½ days	Demo of mobile device and in-mask beacon interaction.

In the following, the studies will be described in greater detail, putting focus on those studies that have become more influential during the analysis. In addition to these on-site studies, written documents that were analyzed for creating the pattern language, are included in the respective sessions.

4.2 Ethnographic Studies

In firefighting training facilities of the firefighters of Paris, intervention exercises allowed to form basic knowledge about the work on the front-line by observing firefighters who performed simulated reconnaissance missions in standard building structures.

Reconnaissance missions are an important part of firefighters' work as they help gathering knowledge about an incident site to inform the ongoing operation. The exercises were performed in the training facility of the firefighters of Paris in Saint Denis, France. The building comprises five floors on a footprint of approximately 120 square meters.

The first exercise took place in a maisonette apartment of the building. The rooms of the apartment are equipped with original interior fittings of bedrooms, living rooms, bathrooms and a kitchen. In the large living room an internal staircase leads to the open gallery on the fourth floor that covers half of the room (Figure 6). To perform the reconnaissance mission, the commander in charge had two teams of firefighters available who engaged the building at the same time. Each team comprised one firefighter equipped with a radio to remain outside the apartment and two firefighters equipped with a complete suite of tools and protective clothing, including breathing apparatus and mask to engage the apartment. For the exercise, the masks of those firefighters were covered with a sheet of sandwich paper that greatly reduced the ability of the firefighters to see and thereby served as an easy means to simulate the limited vision conditions that firefighters face in buildings full of smoke. According to the standard practice in Paris, firefighters who engaged the buildings did not carry radio equipment. The session was videotaped from the perspective of the commander and from each of the teams. To gain an overall view of the incident and to understand the interactions among the different actors, all the three videotapes were synchronized so that they can be viewed at the same time.

The second exercise took place in the basement of the training facility. The basement features a more complex set of small and larger rooms that house heating installations and thereby provide a realistic basement experience for the firefighters. The exercise especially focused on the interaction between two teams of firefighters working consecutively for performing a

Figure 6: Firefighters performing a reconnaissance mission

reconnaissance mission and therefore included the need for a hand-over. During the operation, a commander remained outside the building on ground level while two teams of two firefighters performed a reconnaissance mission in the basement of the building, one after the other. Firefighters used their standard equipment. Again, their masks were blindfolded, so that they hardly could see the environment (Figure 7). The exercise was captured with two parallel video camera recordings that followed the engaging team from different perspectives. As the basement has no windows and lights were sometimes switched off, the cameras shot video using infrared lights and sensors.

For both exercises, a time-referenced transcription and translation of the spoken words as well as an integrated notation of events and statuses in the data supported the analysis of the videos.

Figure 7: Firefighters with covered mask in basement

At the State Fire Service Institute of North Rhine-Westphalia in Münster, Germany, trainers reported on the setup of the novel facility that allows simulating firefighting conditions close to real-world scenarios.

The State Fire Service Institute is the central place for the education of professional and voluntary firefighters of the state. The educational methodology used in the institute is based on the long-term teaching experience of the institute. In the trainings, the school tries to provide tasks to the firefighters close to real-world scenarios.

The novel training facility of the organization is unique in Europe. On an area of 7000 square meters, it provides different training objects for firefighting scenarios, technical assistance and interventions with nuclear, biological and chemical substances (Figure 8). It makes extensive use of computer-controlled simulation technology that allows running dynamic firefighting scenarios in a very realistic fashion. The light of fire, thick smoke or the sounds of victims calling for help can be controlled using software applications running on tablet PCs. The instructor can control programmed scenarios at any time. This also allows pausing a simulation to instantly reflect on mistakes made by the student, and then continue the

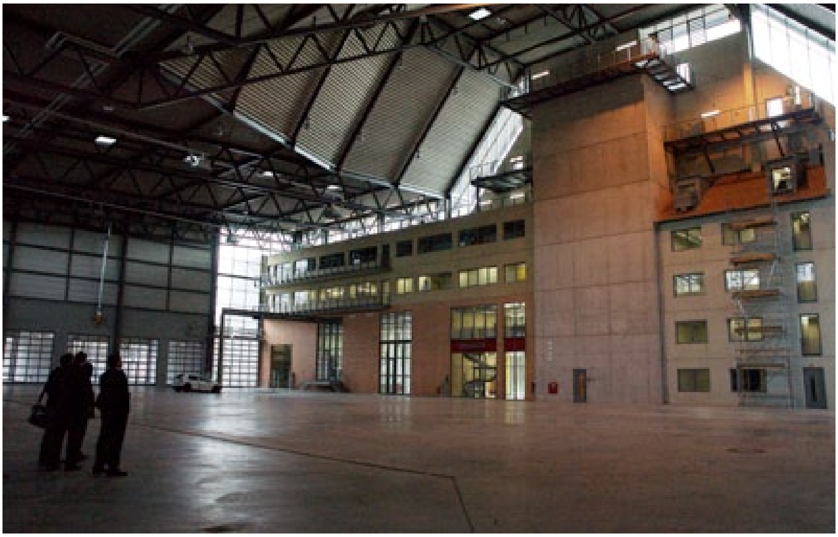

Figure 8: Training facility in Münster, Germany

exercise. The facility offers fully equipped training environments for a single-family house, an apartment house, a high-rise building, a store, a factory, a laboratory, a hospital (Figure 9, right) and an underground garage. In the facility, real fire is not used as the focus is on the tactics and procedures of command and coordination work. At the institute, future commanders learn to take decisions for a company and to deploy their firefighters and resources. Without the dangers of fire, but filled with smoke, flickering lights and the sound of fire and victims calling for help, the simulation technology in the training hall effectively provides an experience that allows gaining a deep but safe insight of firefighting practices and extends way beyond the standard means to simulate environments in small scales (Figure 9, left).

Walking through the different parts of the facility, trainers explained the different aspects of the education and detailed the design and possibility that they incorporated in their novel facility to prepare firefighters for their job.

Figure 9: Modelled and real training environments

With the idea to learn about the practice from the equipment used, official firefighters tools were taken stock of and they were interviewed about the tools that they personally carry.

In a firehouse in Cologne, a firefighter introduced all the tools that they carry on the engines and the ones they use on the frontline. He also started showing examples of tools from the pockets of protective clothing of the entire brigade that was positioned next to the engines, ready to be used in case of an incoming alarm (Figure 10, left). As a follow-up to this initial investigation, a brigade of firefighters was asked about the tools that they personally use at the Firefighting Service Institute in Münster, Germany. Answering questions about their equipment, firefighters presented the tools and directly demonstrated the different usage possibilities. Tools included those that are formally assigned and those that are personally chosen (Figure 10, right).

Despite these workshops especially focused on tools, other workshops allowed for more informal occasions to learn about the tools in use and thereby to gather additional knowledge of the equipment used at the frontline.

Figure 10: Studying firefighting tools

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. Such more casual conversations took place for instance in the central lounge and food place of the firehouse, at the garages, outside the firehouse and at the bar of the Fire Service Institute, the 'Heldenhalle' (hall of the heroes). In these discussions, firefighters frequently referred to the workshops and drew links to real intervention.

In addition to the two focal firefighting organizations, three other firefighting organizations provided insights to other contexts of firefighting work.

In a workshop and interview session, a commander at the firefighters of Bremerhaven, Germany presented the work of his organization. The firefighters of Bremerhaven are also in charge of the container port of the city. The port is the second biggest in Germany and has a turnover of 4.5 million containers per year (Eurogate 2010). The firefighters of Bremer-

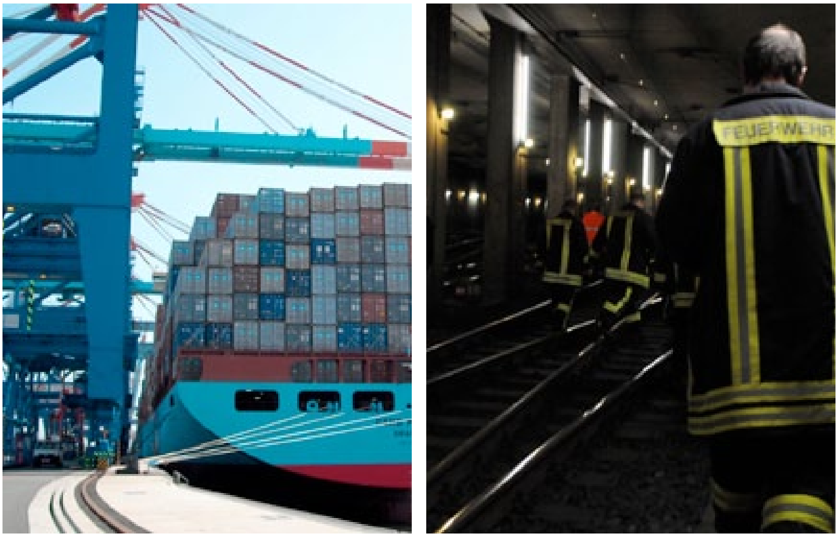

Figure 11: Port and subway environments

haven provide security to all containers marked as dangerous containers. They do on-site checks and may need to secure a container in case the port workers report leaks (Figure 11, left). For this special job, firefighters have a dedicated facility at the port that allows offloading dangerous goods and features decontamination rooms. In addition to the work with containers, firefighters are also responsible for fighting fire onboard vessels while in the port.

Additionally, the firefighters of the city of Bonn, Germany organized a training session in the subway at the central station. Periodically they run these interventions in which firefighters in a nightly workshop, after the normal subway traffic is stopped, can access the subway station and learn about the location to prepare for a possible intervention. In the subway system, special lorries are placed in the system as a vehicle to transport firefighting equipment on the tracks. In the workshop, firefighters learned about the position of these lorries and also about the locations of tracks, light switches and emergency exists (Figure 11, right).

In another workshop, a commander at the firefighters of the chemical plant chempark Leverkusen, Germany introduced the work of the firefighters at the factory. The chemical plant operates its own firefighting crew that is especially trained to respond to accidents with chemical substances. These chemical high-risk installations require continuous safety checks and simulated interventions. The plant also has two control rooms that can operate in complete isolation from the surrounding, in case of a contamination of the plant. Additionally, the firefighters support operations outside the plant when their special expertise is required, for instance in accidents with trucks or train that load toxic substances.

Besides the user studies on-site, written documents that firefighters referred to, were used as input. Especially accident reports but also official firefighting regulations, official training materials and unofficial firefighting guidebooks added to the corpus of empirical data.

Accident reports provide an account of problematic real-world situations and also show in their analysis a reflection of how firefighters see their practice themselves. In their conclusions, accidents reports discuss tragic events in their relation to the existing practice (e.g. (Bürger et al. 2006, Fricke 2009, Moravec et al. 2007, Steingröver 2007)). Other accident or near-accident reports can be found at firefighting online forums that were also taken into account (Feuerwehr Forum 2010, Firefighter Close Calls 2010b).

Official regulations provide an account of the formal framework in which firefighters operate. Here were especially relevant, regulations for frontline work with breathing control apparatuses (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe 2005).

Training materials, as used by senior firefighters to teach their colleagues, as well as the ones provided in unofficial guidebooks, allowed understanding what is relevant for firefighters to prepare for real world incidents (e.g. (Günter et al. 2009, Klingsohr 2007)).

4.3 Empathic Exercises

Equipped with fire-protective clothes, helmets and breathing apparatuses, I took part in four different exercises at the training premises of the Paris Fire Brigade.

The exercises were originally set-up for firefighters with different levels of experience. Some of them were novices while others had followed the same training many times before and also had a lot of practical experience in real-world incidents. Due to these different levels of expertise, the captains thoroughly described every procedure to ensure that everybody was on track and able to follow the instructions. To prepare the exercise, I was required to wear fire protective clothing and breathing apparatus (Figure 12).

For the first exercise, a container was used to show how fire propagates, how to effectively extinguish fire and how to deal with smoke in closed spaces. The container was set on fire and I was able to observe the different states of a fire. Afterwards a captain presented different techniques for using the fire nozzle. In teams we were trained how to use the fire nozzle and to resist the recoil of spouting water (Figure 13).

For the second exercise, I fumbled my way through a tunnel in complete darkness. The tunnel was about 30 meters long and 1.5 meters wide. A fire was then lighted up in the middle of the tunnel. With the breathing apparatus active, I entered the tunnel a second time, guided by a professional firefighter. A rope around 2 meters long connected us. In complete darkness one could only see the fire ahead and fumble the nearby wall. This exercise created a highly stressful setting that was physically and mentally demanding. Walking and crawling I passed through the tunnel following commands of the firefighters who told me how to correctly use the walls as navigational guides.

For the final exercise, I entered a fire simulator designed especially to produce gas-powered fire in a controlled way. The exercise was similar to the previous one but in a controlled environment. In a simulated kitchen, first the oven then the overall ceiling was set on fire. The experience showed the distribution and dynamics of heat in a burning room.

Figure 12: Exercise in St. Denis

The State Fire Service Institute of North Rhine-Westphalia in Münster, Germany allows simulating entire interventions. As part of such an intervention, I acted as incident commander, supported by a professional commander. In the intervention, researchers and firefighters jointly performed a rescue mission in an apartment building.

Before the practical exercises started, a trainer of the Fire Service Institute taught the basic structure and vocabulary used in the firefighting operations. The presentation was followed by an introduction of indoor firefighting tactics from a high-ranked commander of the Cologne Fire Department who also introduced basic firefighting equipment and overall procedures.

The actual intervention began with an incoming alarm call including the type of incident as well as the location of the incident. The company simulated in this intervention comprised a command vehicle, two pumpers, a turntable ladder and a total of 22 firemen out of which half were professionals. On the way to the incident site, with sirens turned on, the teams had to prepare their actions.

After reaching the incident site, I, as acting incident commander, had to get an overview of the situation and to assess the structure of the site and

Figure 13: Exercise in St. Denis

the incident as well as information available from witnesses on site. The task was to manage all the teams and oversee the overall process.

Teams had to provide the infrastructure for the incident response work. They had to bring the ladder in a safe and correct position, ensure water supply and prepare the hoses. Others started entering the building, both over the front door and the ladder, with the task of searching for the missing person (Figure 14). The mission was accomplished once the missing dummy was rescued from the building and the company had been prepared for the next intervention.

In addition to working as incident commander, I also joined exercises as a frontline firefighter both in the training facility State Fire Service Institute as well as at the firehouse in Cologne.

At the State Fire Service Institute a professional firefighter and I scanned a basement of an apartment for potential victims and, after finding a missing person, carried a dummy victim back to the outside (Figure 15). During the intervention the firefighter explained what he did and told me when I deviated from the normal behavior or performed potentially dangerous actions.

Figure 14: Simulated intervention

At the firehouse in the fire station of Cologne, we formed an attack team of three researchers to engage and scan the basement of the firehouse without any outside support. Here, the occurring problems made visible the work that in the previous experiments was performed by the professional firefighters without notice.

The firehouse in Cologne features a breathing training course to ensure physical fitness of firefighters before using breathing apparatuses in real interventions and a heat training facility that allows creating the same thermal conditions that firefighters face in burning buildings. I participated trainings in both setups.

The breathing fitness course comprises two different tests. First, a moving ladder and a hammer machine are used for physical workouts when wearing breathing apparatuses. Second, a cage structure provides a two-story labyrinth, where each level is about one meter high. In it, firefighters have to crawl through tunnels both horizontally and vertically and open doors and hatches to change rooms and floor levels. While crawling, the breathing apparatus might get caught with the surrounding fence, also the tunnels

Figure 15: Frontline work

might require firefighters to take off their compressed air cylinder and, in complete darkness, put it back on. I took that training that is observed by a trainer via infrared cameras and microphones so that he can at any time provide support if panic occurs.

For the heat training, cargo ship containers are connected and thereby form a metal house (Figure 16). In two of the containers fire is sparked, burning wooden cargo pallets and thereby heating up the entire installation. The containers feature ladders and obstacles over and through which firefighters have to move themselves and heavy goods such as fire extinguishers. The construction has emergency exits at which barrels of water allow the firefighter to cool down. Besides lifting heavy goods in a realistically hot environment, the set-up also allows to extinguish fire indoors. While the burned materials do not produce the same black smoke that plastic materials produce, the air in the container is still toxic and will be fatal to a person entering without breathing apparatus. For this risk, firefighter only use especially approved breathing apparatuses that are more frequently checked due to their heavy physical load. While I took the exercise, a firefighter prepared my equipment and continuously observed my actions and stayed

Figure 16: Heat training facility

close to support me in cases of problems (Figure 17). After the initial intensive training, I engaged the heat training facility again at a later workshop.

4.4 Triggering Artifacts

The Digital Command Post is a wizard-of-oz location tracking system that allows the incident commander to see on a large screen the current positions of his subordinated frontline teams as part of an interactive, three-dimensional map of the training facility. Three simulated interventions were performed using that system, involving two or three teams on the frontline and the incident commander.

In current visions of technology researchers, the commander of a firefighting operation can continuously monitor the status of the operation by knowing about the current position of all his team members and other local information on large displays showing a digital visualization of the incident site (Discovery Channel and Wired Magazine 2006, RUNES Project 2006). The exercises with the Digital Command Post were designed to introduce

Figure 17: Preparing for heat training

such an envisioned ubiquitous computing system to support firefighters during indoor operations and explore the effects that this change experiment produces.

The Digital Command Post showed all five floors of the training facility as two-dimensional maps vertically aligned in the virtual space. Using the touch surface of the screen, the incident commander could change the zoom level and control the rotation and position of the virtual house. Also, a pencil tool allowed drawing on the active floor so that the markings would become objects in the virtual world that could be moved along with the model of building. As input data, the system required a continuous stream of location information of a particular firefighter in the building. Wizard-of-oz facilitators, who followed the firefighters during their way through the building, used tablet PCs to mark their current position on a map and thereby generated this geo data (Figure 18). The location information was transferred via a wireless network that covered the entire facility to the large display at the command post (Figure 19). The command system was set-up at the training center of the Parisian firefighters in Saint Denis. The system was placed in a separate building close to the training facility.

Figure 18: Wizard generating location data

Adding to this change of introducing a new digital system, and as another change to the regular reconnaissance exercises run by the Parisian firefighters, one of the two firefighters in the building was equipped with radio so that the commander could not only see the position of his team but also communicate to them.

To drive this interaction, firefighters received the mission to find bottles inside the apartment on the third floor of the training facility. The position of bottles were registered in the command post application and therefore known to the incident commander. He had to guide the team to find the bottles. Firefighters had their masks covered to block their sight.

The sessions were videotaped from two or three perspectives, capturing the commander interacting with the command post application and his team via radio and following the teams inside the building. Additionally, the movement data generated by the facilitators following the firefighters was stored and plotted on a map.

To compare more traditional support with the Digital Command Post, another simulated intervention only introduced a static, paper-based map and radio equipment to support the firefighters in finding target locations on-site.

Figure 19: Command post display

This exercise was setup to learn about the influence of a map-guided command on firefighting reconnaissance missions. As the previous exercises, the mission took place in the training facilities of the Parisian firefighters in Saint Denise, France. The incident commander received a paper-base map of the second floor of the training facility. In it, markers showed the positions of the bottles hidden in different rooms. A rope connected the team to another firefighter who remained outside the building. Again, the exercise was videotaped from frontline and command perspectives.

Currently, some ubiquitous computing systems exist as commercial products, yet they have not made their way into firefighting practice. A novel commercially available egress transmitting system to support the tracking of lost firefighters was tested in a scenario where a team on the frontline faces sudden problems and needs to be rescued by a backup team.

The egress transmitting system by Dräger Safety (2009a, 2009c) that has been presented earlier as related work, comprises two different kinds of components. First, a number of beacons can be freely placed by the firefighter. Once activated, the beacon emits radio signals, starts blinking and periodically produces a sound signal. Second, a device is permanently carried by a firefighter and displays the estimated distance to the closest beacon. Additionally, the device has an emergency button that the firefighter can press to notify colleagues when he needs help. The device then triggers a high-pitch audio alarm and can be traced by other firefighters using a second of these hand-held devices. To track another firefighter, the device can be switched between modes to either show the distance for the closest beacons or personal devices in rescue mode.

The system is commercially available yet has not made its way into the daily practice of fire brigade we worked with. The egress transmitting system was therefore tested at the training facility at the State Fire Service Institute in Münster, Germany in a town house structure. Initially, firefighters tested the system by simply searching for a hidden beacon in a basement room and using the handheld device to track and find the beacon. As the basement was filled with artificial smoke, the view was blocked and firefighter could not see the beacons from more than one meter distance and had to rely on the information from the hand-held device to find the missing beacon (Figure 20).

Then, in a complete scenario, firefighters used the system to support a simulated mission of a back-up team. Fully equipped with their standard gear and making use of the beacons, a team of two firefighters was instructed by the incident commander to engage the apartment on the second floor and perform a search and rescue mission. Having scanned the apartment partly, the team was told to report an accident and to ask for outside support. Following the request from the frontline, the incident commander sent a back-up team that was on stand-by to support the colleagues. The back-up team was also equipped with a handheld device and thereby could track the team following the signals of the beacons and the device from the missing firefighters.

The mission was captured with video, closely following the two teams and making use of the infrared video recording mode to increase visibility in the rooms full of smoke.


Figure 20: Testing egress transmitters

At the State Service Institute, a company introduced their training system, originally for military purposes, to a team of voluntary firefighters to explore a potential market.

To use the system, each firefighter wore a vest that holds a number of reflectors. In the rooms of facilities sensors were attached to the walls that form a sensor network and can detect the nearby firefighters. As with the Digital Command Post, outside, the trainer could track the location of the crew inside the building. The exercise was performed by a voluntary firefighting crew and observed by a number of high rank firefighting officers from firefighting stations of the German state of North-Rhine Westphalia. After the simulated intervention, firefighters reported on their experience and the commanders commented the usefulness of the system as means to support the training of firefighters.

Other products or components of potential systems are available on consumer markets but have not been adopted for firefighting use. Jackets with interactive textiles were handed out to firefighters and after-use interviews were conducted.

Firefighters received a jacket that has an integrated MP3 player and can be controlled using pressure sensitive buttons integrated into the fabrics. Firefighters had a chance to test them for several months, and were later interviewed in groups of four at the firehouse regarding their experience and the potential use of such interactive in their work. Here, the focus was not on the design of that particular system; rather, the idea was to spark a discussion about the relation between such interactive technology and the nature of the frontline work.

4.5 Design-Oriented Activities

The frame for this research and an instance of a development of a ubiquitous computing system for frontline firefighters builds a cooperative research between firefighters, industry and academic partner organizations, jointly developing a navigation support system for the frontline.

Besides the studies described in the previous sections, 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 et al. 2009).

The project 'landmarke' has been funded by the German ministry of Research and Education as part of their security research program and brings together the firefighter's of Cologne, the Fire State Service Institute in Münster, the companies Dräger Safety, one of the world market leaders in firefighting equipment (Dräger Safety 2008a), interactive wear AG, specializing in interactive clothing and Winckel, a company specializing in RFID technology, with the academic partner of the TECO lab at Technical University Karlsruhe, BIBA lab at University of Bremen, the University of

Figure 21: In-mask and handheld interaction

Siegen and finally the Fraunhofer Institute for Applied Information Technology.

As part of this project, and as an investigation into the field of human computer interaction techniques for the frontline, experience prototypes for visual feedback inside the breathing mask and a visual hand-held device to interact with the beacon-based navigation system, have been designed and discussed with firefighters. While the initial prototype tested the positioning of an LED in the mask (Figure 21, left), the second prototype showed the strength of the radio signal of a selected deployed beacon to the firefighter on a LED bar integrated into the display. Also, the information was displayed on a hand-held device that was intended to become arm-mounted in the long run (Figure 21, right).

In the scope of the project, several participatory design workshops were conducted where firefighters and researchers jointly discussed and tested the novel navigation technology (Figure 22). While the patterns described in this thesis should inform the design of ubiquitous computing systems beyond this focus on navigation, the project provided a frame in which aspects of this work become manifest in technological artifacts. The impact

Figure 22: Design workshop

and relation of the pattern language and system designed will become part of the discussion.

5 A Pattern Language

Linked up as a pattern language, 16 patterns describe the configuration of frontline firefighting. The patterns detail how firefighters organize the division of tasks and roles, how they deal with information in a dynamic environment, how they form a social binding and how they improvise, provide safety and prepare their work.

The pattern language comprises 16 patterns.

The following patterns are part of the pattern language: FLUID ORDER has become the core category or theme, a meta pattern that describes a fundamental balance between strictness and openness found in frontline practice. RIGID STRUCTURE, INDEPENDENT UNITS, and PROCEDURES show how firefighters divide roles and tasks. The patterns EVER-CHANGING PUZZLE, TAKE GOOD CARE, SHARED ESTIMATES and MONITORING describe how firefighters collect and deal with information in a hazardous, dynamic environment. BIG FAMILY points to the social relationship in the brigade. MULTIMODAL ACTS, MASH-UP, and HANDY MULTI TOOLS address the often-improvisational character of the physical work on the frontline. BACKUP TEAM and THE WAY BACK provide safety solutions for the dangerous work. EXERCISE, and LEARN BY MISTAKE finally bring means to improve and evolve frontline firefighter work.

The identification of patterns greatly benefitted from the broad variety of data, the combination of approaches and from having insights from two different forces.

The workshops produced a large set of empirical data. 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.

Some of the patterns (RIGID STRUCTURE, MASH-UP, MONITORING, PROCEDURES, THE WAY BACK, TAKE GOOD CARE and EVER-CHANGING PUZZLE) were already easily visible while observing the trainings. For 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, I only identified first hints when actively taking part in the actual work (MULTIMODAL ACTS, SHARED ESTIMATES and BIG FAMILY). Using these hints as motivators for more specific interviews or the introduction of technology, allowed to deepen the understanding and verified or corrected personal experiences. Other patterns (INDEPENDENT UNITS and HANDY

MULTI TOOLS) again, were only identified first in the statements of firefighters after the introduction of 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 differently with in real interventions. These patterns could be verified by taking part in exercises that followed the original procedures. Finally, some patterns gained relevance through their omnipresence in the different workshops (LEARN BY MISTAKE, EXERCISE and BACKUP TEAM).

The different approaches of ethnography, empathy and change, thus, became relevant for each pattern in a unique combination and together supported the identification and saturation of the patterns and their interactions. This combination becomes visible to the reader in the data sources used to describe the context of the patterns.

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, the wider perspective enabled to describe, on the one hand, the general principle how firefighters address a mutual problem and, on the other, the variety of how a certain pattern could be implemented in practice. The comparable conditions under which both forces operate in burning buildings, allows presenting their solutions in the patterns side-by-side.

The process of theoretical sampling, however, was not always as clearly planned as the above might suggest. While designed experiments and artifacts produced deeper insights for a specific phenomenon–such as for the studies of firefighting tools–in other cases, a personal experience in an empathic exercise developed new insights and theoretical sensitivity that could be used as an analytical lens for the 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 I looked at 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, I imagined and discussed with others the overall language as a manual for a group of novices that were confronted with the task to fight fire, telling them how they need organize and act in order to stay safe and accomplish their mission. This scenario especially supported the definition of the structure of the language.

The links between the patterns can be visualized to provide an overall view of the pattern language.

Links between patterns form the overall language and relate the pattern to each other. In some cases, links indicate that a pattern on a lower level is a sub pattern of another pattern, in other cases links show that a pattern on a lower level is required by the pattern on the higher level. At the end of each pattern description, a paragraph describes these related patterns and the links between them.

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; indeed they are in some cases a matter of a chosen point of view. There is, for instance, no absolute measure to define if the pattern RIGID STRUCTURE is superior to the pattern INDEPENDENT UNITS or vice versa. Additionally, the missing spatial relation makes it difficult to define certain patterns unrelated. Indeed, as proposed by grounded theory, the links between the patterns are not findings, but hypotheses open for further research.

In this spirit, the figure of the pattern language makes visible the links between the patterns as they are proposed in the descriptions of the patterns (Figure 23). 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 or depend on each other and only in their interaction form a balanced whole.

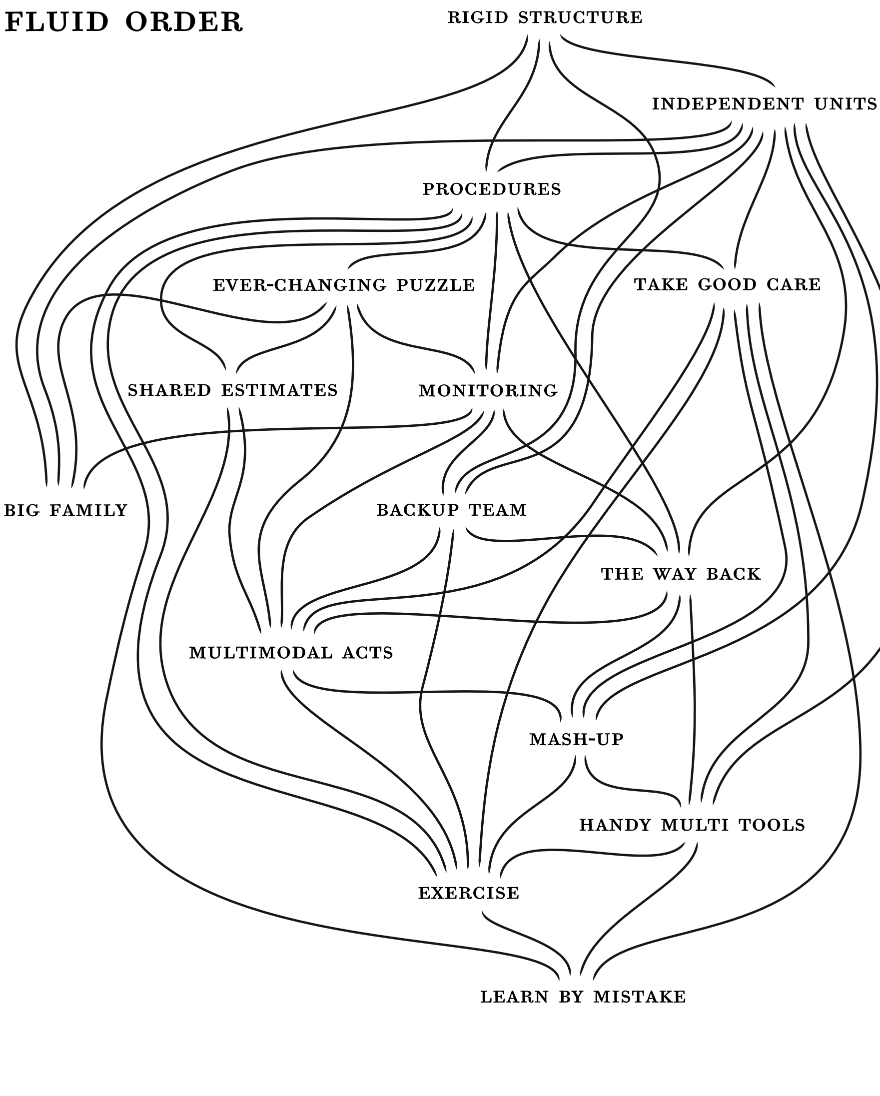

Figure 23: Pattern language of frontline firefighting

The format for presenting the patterns is rooted in Alexander's original pattern format, yet also pays respect to the grounded theory methodology and therefore draws a close connection between the empirical data and the properties of a pattern.

In 'A Pattern Language' Alexander (1977) suggests to make a description of a particular problem the central part of a pattern. To do so for his patterns, he refers to a variety of sources that describe the problem that the proposed solution helps to resolve. Different from this approach, for this research, the central focus is on presenting results stemming from empirical data collected. Therefore, in the following, the central part of the pattern is a description of the properties found in firefighters' actions that make up the pattern. Sometimes, this includes a description of the problem, as suggested by Alexander. In these cases, the empirical data has directly revealed a problem or force that the pattern helps to resolve. This is often the case when new technology introduced to existing practice caused breakdowns. In other cases, however, the empirical data only points to a solution, and may not directly reveal the underlying problem. Here, links between the patterns that create the overall language help to build an understanding of the need for a specific pattern.

In the following, each pattern is identified with a short capitalized title that comprises up to three words pointing to the essence of the pattern, as Alexander suggests. Following the title, the pattern starts out with a summary in italic, split in two parts. The first part describes the context in which the pattern applies, eventually defined by other, related patterns and provides a description of the forces that the pattern helps to resolve. The second part provides a summary of the actions by the firefighters. On the facing page of title and summary, a photo illustrates the pattern.

In its main part, the description of the pattern is grouped by headlines into the different aspects that it comprises, representing the 'properties' of the categories for grounded theory methodology and resembling Alexander's concept that patterns are actually made up by other patterns. The descriptions of the properties directly refer to the empirical data and present selected examples of situations or statements from the field studies. For some properties, pattern references link contents to aspects described in other patterns.

At the end of each pattern a section explains all links to and from the pattern in detail. The links between the patterns are the building elements

Figure 24: Firefighters learn how to deal with the dynamics of a fire

FLUID ORDER

Firefighters are called when something has gone wrong, when systems are out of control. They need to react quickly to prevent further harm in an ever-changing, life-threatening work environment.

Therefore, firefighters respond to the challenge they face in a fluid manner. They apply existing tactics and former knowledge where appropriate yet need to be aware of the uniqueness of the incident and change the operation according to the situation at-hand. The incident shapes the operation and the operation is shaped according to best practices and experience.

Firefighting is about restoring order.

As a firefighter explained, all other systems, installed in society to prevent accidents from happening, have already failed when firefighters are called. The firefighters' task is then to prevent further harm from people and buildings.

And firefighters need to do so quickly.

A firefighting operation is time critical. Fire develops rapidly and there is only so much time to rescue people. In a standard room, a person can only survive for less than 17 minutes after the fire has started (Beyerle et al. 1978: 181). That is why firefighting regulations define the maximum time below 10 minutes to reach an incident site after being called in a downtown area (Schmiedel 2010).

Time pressure is also an issue as the frontline operation itself is limited in time. On the frontline, equipped with a standard breathing apparatus, a firefighter has a total of about 30 minutes to make his way to the target location, do whatever he is supposed to do there, and return. Additionally, he is supposed to keep air as backup. This is a very limited time range, considering that the firefighter cannot walk upright, as he has to crawl to prevent high temperature in the upper parts of a room and to remain safe in an unknown space with limited visibility.

Firefighters confront the chaos with order.

The firefighting structure unfolds immediately when the massive trucks arrive. Starting from a safe spot, firefighters work to bring back order into chaotic spaces. This element of order is present in the patterns: RIGID STRUCTURE, PROCEDURES, MONITORING, BACKUP TEAM, THE WAY BACK, EXERCISE and LEARN BY MISTAKE.

At the same time, each operation is unique, standard solutions may not apply; the operation has to adapt to the situation on-site.

Once arriving on-site, firefighters may need to work in hazardous places completely unknown to them. The context on-site is unique and holds unknown threats. Additionally, an intervention does not face a static context; the incident may develop in unforeseen ways.

Firefighters confront the unforeseeable with improvisation.

Given that standard mechanisms or safety solutions have already failed in cases when firefighters are called, a firefighter underlined that standard procedures are not enough. "We have to improvise", he said. This improvisation and reaction to a dynamic environment is present in the patterns INDEPENDENT UNITS, EVER-CHANGING PUZZLE, TAKE GOOD CARE, SHARED ESTIMATES, BIG FAMILY, MULTIMODAL ACTS, MASH-UP and HANDY MULTI TOOLS.

In interaction with the incident, the order becomes fluid.

Firefighting operations hold a strong inner order that they impose on chaotic situations. Yet, at the same time, this order dynamically adapts to and is shaped by situational needs. The order imposed by firefighters becomes fluid in interaction with a dynamic environment (Figure 24).

The pattern FLUID ORDER is a meta pattern that summarizes all the other patterns.

Figure 25: Helmets showing different ranks of firefighters

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.

A role is assigned before starting the work.

Before starting a shift, firefighters have to sign in for the role that they take during a shift. A strict handover protocol makes sure that all roles are manned and that there is no moment of ambiguity about who is serving on what role as alarms may come at any moment. A firefighter can have the qualification to serve in different functions. A lower rank commander might be able to serve in a higher rank if a superior commander is off duty or on vacation. The role is also defined by the physical and health conditions of a firefighter. Having a cold or a lack of fitness might make the firefighter unavailable from taking a position that requires work with a breathing apparatus; however, he may still serve as a medical assistant or driver in the ambulance.

Every role has its fixed place in the hierarchic overall system.

Starting from the smallest unit of two or three firefighters in a team that enters a building, there is always a clear ranking of the positions to define who is subordinated to whom. Colored stripes on the shoulders and markings on the helmets (Figure 25) provide an immediate visual indication of the rank of the person and distinguish the firefighters in their otherwise similar clothing.

Along with each role comes a set of procedures and tasks.

The role defines the seat in the car that the firefighter is going to take; it defines whether he is going to be on one of the teams who is engaging a burning building. For a large part of the work the crew already knows what to do. After a training situation where the crew lined up behind the car to receive their orders, as the protocol suggests, a firefighter noted that this is different in the real incidents. "Once we arrive onsite everybody seems to be gone", he said, "we already know what we have to do."

The role defines the tools that a firefighter carries.

A team lead of a Cologne firefighters is for example the only one in his team who carries a radio, a team lead in Paris is the one to whom the lifeline, a rope that he carries to find the way back outside, is directly attached.

While such tools are part of trained tactics, firefighters also carry tools that are not officially assigned or predefined from training but personally chosen. As with the assigned tools, these personal tools show clear reference to the role of a firefighter. We found an incident commander carrying earplugs to protect from the noise and a cap to protect from the cold while standing outside, while a team lead who would engage in a burning building joked about those tools and instead brought shortly cut seat belts as a multi tool for carrying victims and also, as he noted, to be prepared in case one of his subordinated teammates forgets holders to fix a heavy water hose to a handrail.

Along with the role comes a set of responsibilities.

A firefighter expressed his responsibility as a team lead inside a building. "I am the team lead and I decide what happens in the fire," he said. Providing an example case, he underlined that aspect.

> [I will say:] Guys, only so far, make no further step. And in three more meters there lies somebody [who needs help]. Nevertheless, I say stop, as the thermal is too high. Then the person who lies there has bad luck and if anybody of the other two continues, he will get punched on the nose, as the team lead holds the responsibility for the engaging team. He also takes care that the team stays together. Imagine you go into some building [as a three man team] and all of a sudden you recognize that we are only two. I cannot look again into the eyes of the women, wives. We all know each other, after all.

On the one hand, he is the person making the ultimate decisions for his team; on the other, he is responsible for the safety of his colleagues. Subordinates need to trust the experience of their superiors for making safe decisions.

The structure does not change. Roles are linked to personal behavior.

As already indicated by the tools and clothing, the role usually does not change. In the studies, usually the highest ranked firefighter led a discussion or report first, lower ranked firefighters will help or add notions, in case the higher ranked firefighter cannot provide the complete answer.

In an exceptional case, a firefighter (FF2) who was not leading the team was surprisingly active during performing a mission; often guiding his team lead (FF1) as in the following sequence where the team was trying to find the way back.

FF1	There is a wall. (5 seconds) A door.
FF1	On the right.
FF2	Left. Wait, wait, it is this way.
FF1	There is a hallway.
FF2	No, it is this way.

The leadership shown by FF2 in making the final decision where to go presents an exceptional case. As it turned out later in other training exercises, FF2 usually is a team lead himself and had only for that training mission taken the subordinated role. He remained in that role even when he became subordinated for this training session. While a firefighter might have the qualification to occasionally serve in a higher rank if a superior commander is off duty or on vacation, he usually would not take a lower ranked position.

For firefighters the structure is the normal case.

In the workshops where researchers and firefighter jointly performed mission, firefighters quickly imposed their known structure on the newcomers. Sitting in the engine before the intervention the highest ranked firefighter in the car created the organizational structure with the following statement:

> We form a three-man team as the water team. Then we have a three-man team as hose team. That means your task is to create the water supply from the water source to the pump and from the pump to the distributor; your task is to prepare the water hose for the two of us and we two will equip us with breathing mask, breathing apparatus and the other equipment and will then proceed to do the firefighting.

The structure is also manifest in the way people reach higher professional levels.

From becoming a firefighter, to commanding an incident, firefighters gradually have to get promoted to make their way up the ranks. A team lead of an engaging team, for instance, is required to have a certain amount of experience. Especially younger firefighters who want to get promoted, reported that this is not easily possible. Only at the higher levels of administration, firefighters are directly appointed senior positions based on their level of formal education.

The structure is important beyond the operation.

As firefighters stay together during night and day shifts, the fire station becomes a second home; firefighters form a BIG FAMILY.

The pattern RIGID STRUCTURE links to INDEPENDENT UNITS, PROCEDURES, BIG FAMILY and BACKUP TEAM.

Specific parts of the RIGID STRUCTURE are INDEPENDENT UNITS that provide required agility despite the rigidity and BACKUP TEAM that provides a layer of safety to INDEPENDENT UNITS. Forming the social bond of RIGID STRUCTURE requires BIG FAMILY. RIGID STRUCTURE requires PROCEDURES to define firefighters' actions related to the role that they hold.

Figure 26: Two firefighters working on the frontline

INDEPENDENT UNITS

As a result of the extreme conditions of the environment, frontline firefighting is an isolated activity. The perceived situation in a burning building is so eminently unique that others cannot put themselves into the position of the individual working on the frontline. This makes it very difficult to give detailed top-down instructions in a RIGID STRUCTURE *from outside.*

Therefore, small work units of two or three firefighters work very close with each other and only receive general missions. Detailed decisions are left to the unit itself.

In the beginning of an operation, there is only little information that an engaging team could benefit from.

Usually the operation starts on the basis of scarce or incomplete information. Incident commanders are advised to learn from all the information available. Bystanders, or people in the building may be able to provide more information. Nevertheless, a lack of information remains a central challenge to the work of firefighters.

And indeed, the engaging team is also sent in a building to learn about the situation.

The practice of the Paris brigade, who at the time of the study had not established radio as a standard for engaging teams, greatly relies on reconnaissance teams who engage a building without a water hose and create a path for the subsequent teams using a rope.

Orders given by commanding people leave open the detailed actions.

The teams engaging in a building receive orders such as this formal command:

> Attack team one, engage on a life-saving mission, with CABA [compressed air breathing apparatus], with the first C-hose, on the third floor, over the staircase.

Here the commander follows a protocol that specifies the addressee, the mission, the equipment, the target floor and the way of access. In this case, the command specifies an operation using a breathing apparatus and thereby enacts the safety regulation for such missions and it specifies that people are possibly in danger and thereby also enacts regulations that allow to refrain from certain safety measures (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe 2005).

In a less formal way, a French incident commander (IC1) gave the following command to his subordinate commander (IC2) positioned closer to the building.

IC1	via radio	Your mission: Do a reconnaissance of the entire second floor and go on to the third floor if there

		is access to the third floor. So I can send a team to the third floor directly. Do you copy?"
IC2	via radio	Copy that, captain.
IC2		Did you guys understand? So you just scan the second floor, once you find a way that leads you to the third floor you can come back. You go to the third floor and then back down. OK?

In both variations, the engaging team only receives a general mission of what to do, in the first case to safe people, in the second to perform a reconnaissance and find an access to the third floor.

Once engaged, firefighters become isolated in a hazardous environment.

When a team enters a burning building it has to pass a barrier of smoke, before which it has to connect its breathing apparatuses. This may be in front of the building or, in case of a high-rise building, in the floor below the actual fire. After passing the border (Figure 26) the team works in an environment that isolates them from the outside by high temperatures, limited visibility, toxic air and threats posed by possible changes of the building structure. This is especially significant for teams engaging without radio contact. Here, the only connection to the outside world is a rope and a small horn that the Parisian firefighters carry to let their outside colleagues know that they should stretch the lifeline and thus provide a clear direction back. But also in the case of available radio devices, there is only very limited connection between the frontline and the higher levels of command. The radio devices are difficult to use with firefighting gear and a firefighter has to stop crawling in order to search for the microphone, press a button and speak. A commander said: "You can make them pretty busy when you ask them too much." Additionally, the building structure negatively impacts radio connections and talking therefore simply wastes otherwise scarce compressed air.

This isolation allows for local decisions, for dynamic strategies.

On the frontline, firefighters have room to improvise, to deviate from trained tactics, if found necessary. As an example, a firefighter on the frontline saw the shimmering light under the door of a room across the hallway. While the researcher whom he guided followed the previously trained right-hand rule, where the firefighter always follows the wall on his right, the firefighter reported later that in this case he would have deviated from the rule, as a means to find the fire faster.

The perspective on the frontline is very difficult to understand in full from a non-local perspective.

Even with knowledge of the exact position of the firefighter and a map of their work environment, subtle differences between the perspectives on the frontline and from outside may causes severe problems. In a reconnaissance missions, for instance, a commander told his team to turn left and then right to reach a living room. Without sight, firefighters did not make a 90° turn as envisioned by the commander but instead turned 180° into another hallway and ended up in a different room. As the following dialog shows, perspectives diverged, reference points such as "the wall" are difficult to be aligned, and it was the understanding of the location formed by the firefighters on the frontline that finally helped to solve the problem.

IC	via radio	After you left the kitchen, on the left you found a corridor, you continued right, and did not follow the wall. Did you do that?
FF1	via radio	Yes, yes. Yes we did that and then we went right, as you told us.
IC	via radio	Then you should find the victim.
FF1	via radio	OK, we search.
		FF2 touches a bed.
FF2		What is this? … It is
FF1		What is this? We are here, we are here, here we are in the bedroom.
FF1	via radio	Here we are in a room with mattresses.

While in this case, the commander only had a paper map of the environment, even in exercises with the Digital Command Post that provided flawless feedback on the firefighters positions, a firefighter stated after the mission in an interview that he "was afraid that there is an offset on the screen", and thereby expressed his reservation towards being directed from the outside.

On the frontline, the integrity of the unit is absolutely vital.

For a unit, comprising usually two people, it is absolutely crucial to stay together. Firefighter continuously put effort in staying together and knowing about the other, a difficult task in this isolating environment. As the accident report of an basement fire in which one firefighter died, shows, even teammates who are physically very close to each other can face difficulties in knowing what is going on with their partner (Moravec et al. 2007). During the exercises, firefighters repeatedly state: "the most important thing is that we two stay together." Another near accident report calls the splitting of a team as a "mortal sin" (Fricke 2009: 9).

On the frontline there is no alternative to the unit.

The pattern INDEPENDENT UNITS gets referred to by RIGID STRUCTURE and links to PROCEDURES, TAKE GOOD CARE, MONITORING, MASH-UP, BIG FAMILY, THE WAY BACK, HANDY MULTI TOOLS and BACKUP TEAM.

INDEPENDENT UNITS are a specific part of the RIGID STRUCTURE that makes up the overall organization.

In order to be safe, INDEPENDENT UNITS require PROCEDURES such as MONITORING or THE WAY BACK and they additionally need to TAKE GOOD CARE. INDEPENDENT UNITS require a BACKUP TEAM on stand-by; they rely on their comrades as part of a BIG FAMILY. Given their limited resources, INDEPENDENT UNITS require MASH-UP and HANDY MULTI TOOLS.

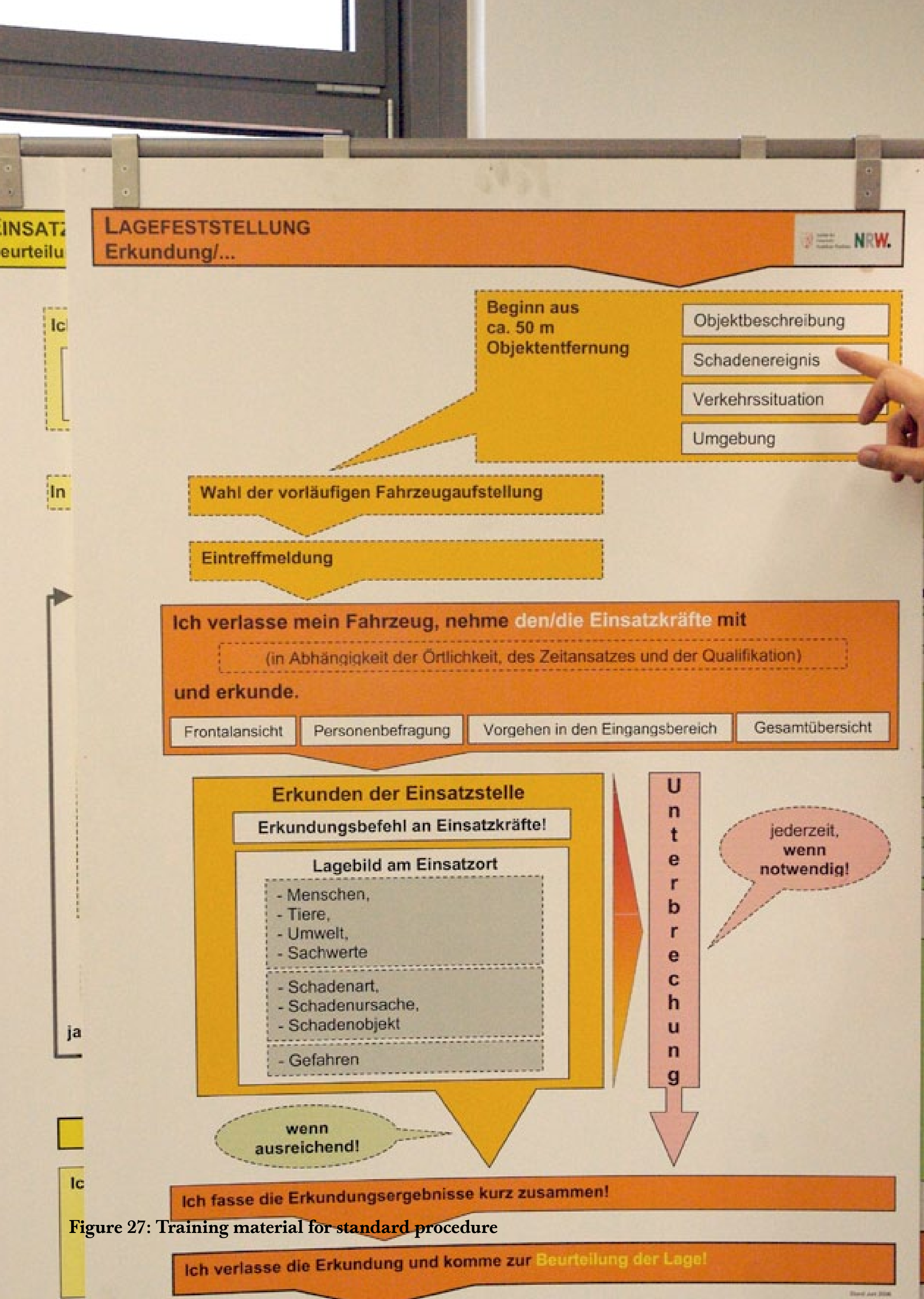

Figure 27: Training material for standard procedure

PROCEDURES

Firefighters need to react promptly; after the arrival on-site, there is only so much time to decide what to do. With a RIGID STRUCTURE *they know who is in charge, now the problem is about deciding how to act. Additionally, they 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.

Procedures cover a great variety of aspects of firefighting practice.

Starting from the incoming alarm until the return of the fire crew to the station, different procedures help firefighters in doing their job.

There are procedures supporting commanders in making strategic decisions.

General rules of how to act, such as described in EVER-CHANGING PUZZLE, form a framework that can be applied to command an incident (Figure 27).

Entire pocket books, e.g. (Günter et al. 2009), are designed to support the commander for on-site in dealing with a variety of situations. Ordered by keywords, the commander finds procedure steps and checklists that help him in different situations.

Besides official procedures, rules of thumb also guide the commanders in making their decisions. Often, such decisions are based on SHARED ESTIMATES.

For the firefighter on the frontline, procedures exist as well.

Even before starting the mission, in a small procedure, teammates are responsible for connecting their teammate's tube from the compressed air cylinder to the mask. For safety reasons, they never make the connection themselves. This procedure does not change with the more novel, pluggable connection, as the following dialog between me (SD) and two firefighters (FF1, FF2) shows.

FF1 Then we have for the masks … one with a screw mount, as you see it is here, and in Cologne, for example, we have a plug mount.

SD And these [pointing to plug mounted mask] you also do not connect by yourself?

FF1,2 One another.

Other procedures to support frontline work include the proposal of a path to take on the front line (THE WAY BACK). Procedures apply in relation to tools that a firefighter carries. Also, procedures suggest, for example, letters that firefighters should imagine to draw in the free space when using the fire hose to ensure that they extinguish the fire in the correct manner.

Procedures span a safety net for the operation.

A number of procedures prepare the operation for cases in which something has gone wrong. As shown in MONITORING, procedures help to identify problematic situations. Procedures ensure THE WAY BACK and make the firefighters TAKE GOOD CARE when fighting fire in dangerous environments. Procedures also will become active, when firefighters face sudden problems with the BACKUP TEAM.

Procedures are important for firefighters and deviation is not always an option.

Firefighters sometimes do not wish to deviate from the trained rule, even if they could do so safely. The potential danger forms a mindset that emphasizes the importance of procedures. In a particular case, a team of firefighters engaged a building using their rope, the lifeline, to build THE WAY BACK. The procedure suggests, that a firefighter outside the building has to stretch the rope before the team inside returns. In the exercise, a team (FF1, FF2) was at the end of a staircase waiting for this to happen when they were ordered back by a commander (IC).

IC	Are you done?
FF1	Yes, but we wait for the lifeline.
IC	We return.
FF1	If we do not know how to stretch the lifeline we cannot follow the command.

While there certainly was the physical possibility to return and follow the stairs down, FF1 decided to follow the trained procedure. The lifeline is a vital tool and so are the procedures for it.

Trainers aim at imprinting procedures into firefighters' minds so that they can recall them immediately in any situation.

As a trainer said, his students need to be aware of the individual steps of the procedures immediately, even when they are woken up in the middle of the night. He underlined the need to act immediately and appropriately at any time. The trainer mentioned that especially for voluntary firefighters, who all of a sudden have to work as firefighters and often have less experience than their professional colleagues, the procedures provide a guide to hold on to in a stressful situation. A firefighter guidebook also points out that "interventions do not come when you are in top form" and therefore defines the mission of the book that should "help to complete interventions in a structured way under bad conditions." (Günter et al. 2009: 3)

Missing or conflicting procedures to deal with new technologies cause problems.

When Parisian firefighters were provided radios, problems arose. In an interview after the exercise the incident commander highlighted the lack of experience and missing procedures when using radio technology:

> There was not a procedure language that says: 'You do this and after this that'. When I gave orders I do not get immediate feedback if you [the firefighters in the building] received them. This is an internal problem since we are not used to work with radios. In the future it should be solved.

A similar effect could be observed when introducing the egress transmitting system that suggests a procedure to find comrades by moving the device in a certain pattern that was compatible with the way firefighters are told to move. Consequently, the device could not provide the promised accuracy and firefighters were misguided by the distance information.

Given the importance of procedures, EXERCISE and LEARN BY MISTAKE become crucial.

Procedures are part of various trainings; they are repeated over and over again as described in EXERCISE.

By learning from accidents and close accidents, as described in LEARN BY MISTAKE, firefighters optimize existing and add new procedures.

The pattern PROCEDURES gets referred to by RIGID STRUCTURE and INDEPENDENT UNITS and links to EVER-CHANGING PUZZLE, TAKE GOOD CARE, MONITORING, SHARED ESTIMATES, THE WAY BACK, EXERCISE and LEARN BY MISTAKE.

Given **RIGID STRUCTURE** and **INDEPENDENT UNITS**, **PROCEDURES** are required to allow firefighters in their different roles to act quickly and in accordance with each other.

EVER-CHANGING PUZZLE is a specific case of **PROCEDURES** for making sense of the overall situation, **MONITORING** and **THE WAY BACK** are specific cases of **PROCEDURES** that provide safety. **PROCEDURES** require **SHARED ESTIMATES** as input for making decisions. **PROCEDURES** require firefighters to **TAKE GOOD CARE** to handle non-standard, exceptional cases. **PROCEDURES** are practiced by firefighters in **EXERCISE** and get improved through **LEARN BY MISTAKE**.

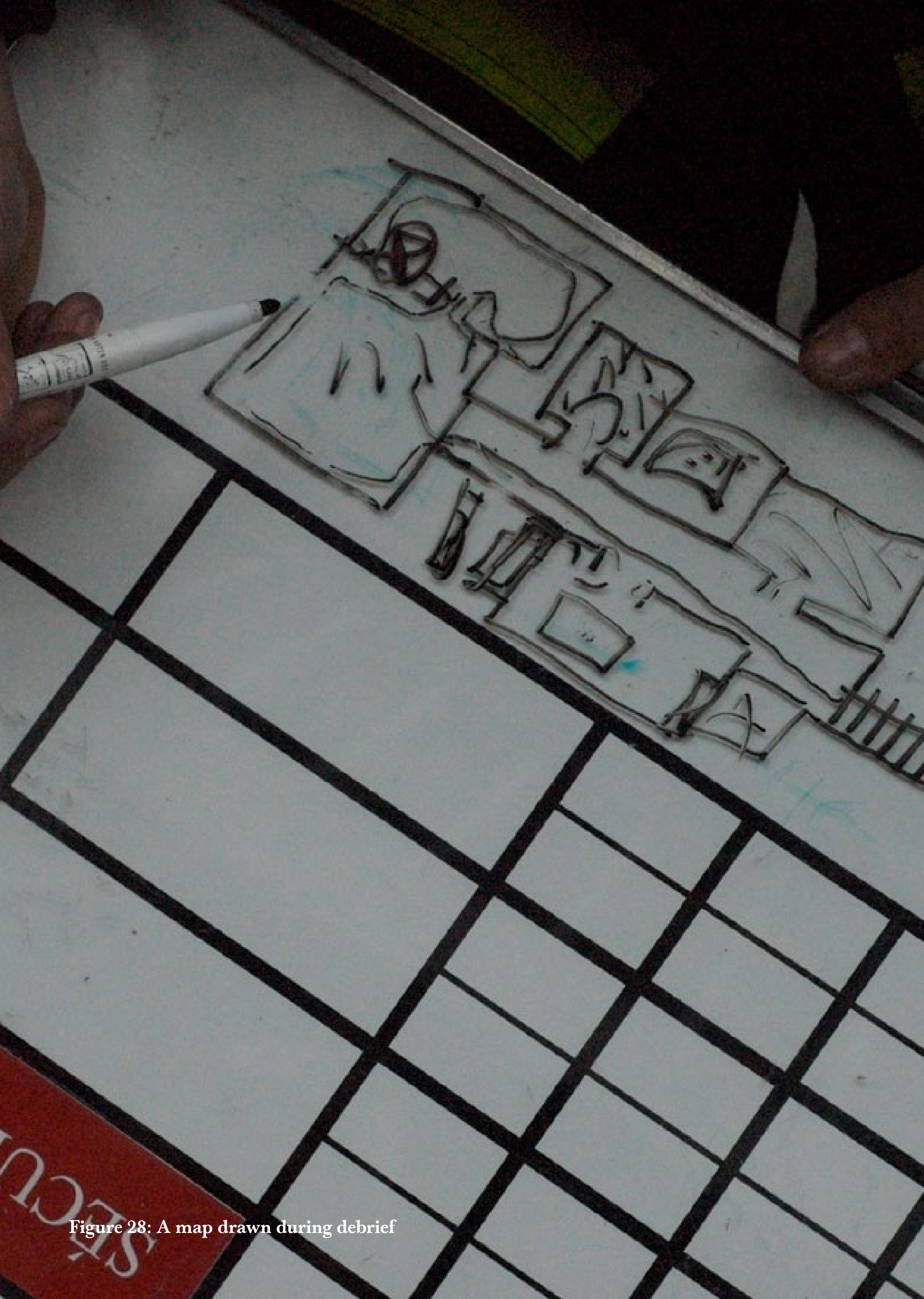

Figure 28: A map drawn during debrief

EVER-CHANGING PUZZLE

An incident changes continuously. As early impressions could be incorrect, appropriate reactions and PROCEDURES *require taking emerging information into account.*

Therefore, firefighters join information from different sources. They gather information from bystanders, people in need, existing knowledge about the incident site and frontline teams. Commanders work on aligning chunks of information to make sense and to form an overall picture of the situation they are in.

When arriving on-site, incident commanders are trained to follow a three-step procedure. They gather information, evaluate and command.

Following a standard procedure firefighters need to understand the situation, decide what to do and then give orders to their subordinated colleagues or report to seniors. In the first step, the incident commander is advised to collect information from all possible sources such as bystanders, people in need, their visual impression, etc. They need to assess the potential danger for people, animals, the environment and building structures. Commanders need to gain knowledge about the kind of danger, the cause and the situation on-site. In the second step, the commander should list all possible dangers. After setting the priorities the overall strategic decision needs to choose between attack, defense and retreat. Finally, a commander should issue orders to the relevant forces.

On the frontline, there is a collaborative effort to build an understanding of the unknown environment.

With limited sight, firefighters on the frontline have to work on connecting and making sense of details (MULTIMODAL ACTS). In the following example, a team had entered an apartment and scanned the rooms. As the sequence shows, the two firefighters (FF1, FF2) collect and share small pieces of information about the environment they are in.

	FF2 touches the door of a desktop.
FF2	There is a metal box.
FF2	There is a wall in front.
FF1	Yes, I also have the wall.
FF1	There is a door.
FF1	I open the door.
	FF1, FF2 enter another room.
FF1	Let's go right.

From these small pieces of information, firefighters try to inform their decisions. In the following sequence, the way in which a door opens is a clue to the firefighter that this is not the correct room.

FF2	Here is a door.

FF1	There is a door?	
FF2	Wait, no, no, yes I have a door. Yes, I think, take a left.	
FF1	Go, we engage.	
FF2	I open the, oh no, wait, it opens from the outside.	
	FF2 closes the door of room.	
	FF1, FF2 continue to walk in the hallway.	

In this situation, FF2 interprets the door that opens from the outside as a signal for a wrong path, probably as a door that provides an exit to the apartment and does not lead to another room.

Similar information pieces are shared, local clues allow to form an understanding of the location and to align inside and outside information.

IC	via radio	You should be in a shared bathroom.
FF2		In what?
FF1	via radio	Yes, there are toilets, OK, I am in the bathroom.

In debriefing situations, firefighters report on their experience and show how they form an understanding of what they have encountered and also, how this understanding is shared with others.

By drawing a map of the apartment for the incident commander, a firefighter recapitulated the mission he has been on. Step by step he connects the experiences made and thereby forms an overall picture. While drawing (Figure 28), the firefighter reports:

> Here is a room full of stuff … seems to be a small room … you only have about 1 square meter to go on … the rest is just rubbish … I fumbled with my hands and dropped some things. Then I came back. Here is the lifeline … what did I do then? I take the lifeline and take it with me. Here I scan the room and make a round in the room. I make one round the room … tac tac tac. […] Here you start, I do not think the room is very big. We get in here, start on the left and here I found the victim. We then stopped the reconnaissance … made another round in that room and continued this way … we scanned this area and walked a bit in the center and then continued. After that I went back and made a small round in this room continued that way and finished all the rooms. So, I have scanned these rooms, and that could be a heating installation. […] We got out and scanned the part. So I did not scan this room as they already found the thing and we went on.

This detailed description shows, how the firefighter builds a map of the basement. The commander then, based on that information, issued orders to the consecutive team to continue the operation.

As detailed in SHARED ESTIMATES, such reports often include estimates to size the environment.

Firefighters continuously check what is going on.

As described by MONITORING, firefighters outside the building continuously take note of what is happening at the frontline.

In this puzzle, small misleading information can have major impacts.

In the experiments with the digital command post and radio devices, information was sometimes interpreted incorrectly. In one case, a commander guided his team up one floor over a staircase. The team reached the fourth floor and a door to the roof terrace of the building. In this phase, a facilitator in his tracking software did not change the floor level, but remained entering data on the third floor, as the floor plans of both floors look relatively similar. At the command post display the commander therefore saw the team still on the third floor while in reality they already had reached the fourth floor. In this situation the commander required his team to withdraw from the apartment and made them take a different staircase. After about 15 minutes of detour, they reached the same place that they had been to before.

The collection of information can be disturbed by technology.

When guided via the digital command post system, a firefighter stated that he was unable to provide an accurate description of the apartment. He compared the exercise that introduced the technology with an exercise on the day before that he performed in the traditional way without technology support:

> Yesterday it was a reconnaissance in the basement. Yesterday I explained exactly what I saw, piece-by-piece, I described the things; I think it was a correct plan. But here I really cannot tell you.

The pattern EVER-CHANGING PUZZLE gets referred to by PROCEDURES and links to MONITORING, SHARED ESTIMATES and BIG FAMILY and MULTIMODAL ACTS.

EVER-CHANGING PUZZLE is a case of PROCEDURES.

In order to receive information for the EVER-CHANGING PUZZLE, firefighters require SHARED ESTIMATES, MONITORING and MULTIMODAL ACTS. For a greater mutual understanding and the interpretation of each other's information EVER-CHANGING PUZZLE requires BIG FAMILY.

Figure 29: A firefighter feels the environment with his leg

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 to the firefighters. On the other, the actions of firefighters could lead to new life-threatening conditions.*

Therefore, firefighters always await the unfortunate thing to happen and take means to prevent it. They constantly consider what would happen in case something goes wrong. Thereby, they are prepared for the unforeseen, keep a high level of attention to the environment.

Firefighters constantly expect bad things to happen.

In one of the training exercises, I was with a firefighter jointly scanning the basement of the facility for the victims to rescue when suddenly, after opening a door of a room, something threw me on my back. A moment later, my professional teammate told me that he had pulled me back to show me what might have happened when I opened such door in a real intervention. While I was stubbornly following the PROCEDURE to scan the rooms one by one, he was reading the signs of environment (MULTIMODAL ACTS) and had seen the flickering light shining through the clearance between doorframe and door leaf.

When opening doors, firefighters might change the air mix in a room. Suddenly letting oxygen float into a room might cause dangerous explosions, a so-called backdraft. As a precaution, they feel the temperature of doors with their hands and use small impulses of water to cool down the rooms and to know about extremely high temperatures at the ceiling if the water evaporates immediately.

You can see the caution in the way firefighters move.

When crawling on the floor, firefighters might fall downstairs, or get trapped in furniture. Therefore they develop special ways of moving . As soon as there is a potential danger and the firefighter is not simply following a wall, firefighters will use one leg to feel their way. In this way, they protect their body from any danger that the environment might pose (Figure 29).

Firefighters must expect irrational behavior from the people that they try to provide help.

Not only do firefighters have to expect dangers from the environment, also people in danger might act irrationally. One example provides the rescue net, that firefighters use in special situations. With this tool, people trapped in burning buildings can jump out of the windows and land safely on the ground. Modern rescue nets are however more complicated devices than mere nets. A bottle of compressed air blows up a cushion pad. The tool, as a critical means to safe people's lives, nevertheless, can also cause harm and make people jump on unsafe ground.

A firefighter explains:

> You have the tie fastening on top, you pull, and from the contents of the bottle the system gets filled up. The set-up time is 60 seconds. That means that within 60 seconds the thing should be entirely unfolded and only then, when it is completely unfolded, do we put it in front of the building. Imagine the following situation: You build it up and roll it out, the resident gets a hot buttock, he jumps, even though the thing is not yet completely built. That's why we built it out-of-sight and only when it is completely ready, we carry it in front of the building.

Firefighters bring tools to the frontline, for the eventual case they might need them as a backup in problematic situations.

A firefighter carried for instance short cut seat belts as a HANDY MULTI TOOL. Explaining why he is carrying them he states:

> The standard case is that I most of the time go into the fire. Then I am the leader. These are not different from seat belts of a car. You always need to fix something. Now, you have forgotten the belt holder or the hose holder, that thing is with you, you wrap it around, pull it tight, then it is also fixed.

Building on previous experience and preventing earlier mistakes (LEARN BY MISTAKE), the tool he carries saves him from bad situation he might be faced with once another tool has been forgotten.

Firefighters envision incidents and things that could go wrong.

In a workshop that took place at the research facilities, a firefighter noted on the way to the cafeteria that he had already looked for the rescue plans and pointed to the fire hydrant in an environment that was previously unknown to him. "We have an eye for that" he said.

Online, firefighters share cases in which environments might cause dangers for firefighters, as the following example shows.

> We responded to a odor of fuel oil in this residential structure. The first picture shows a typical door way. Check out the second picture !!! No staircase to the basement…. The pictures aren't that great (took them with my Blackberry) but if you look closely you can see that a firefighter could be seriously injured just investigating a "routine" alarm. (Firefighter Close Calls 2010a)

The pattern TAKE GOOD CARE gets referred to by PROCEDURES and INDEPENDENT UNITS and links to MULTIMODAL ACTS, MASH-UP, HANDY MULTI TOOLS, EXERCISE and LEARN BY MISTAKE.

Despite PROCEDURES, INDEPENDENT UNITS are not safe, they require TAKE GOOD CARE.

TAKE GOOD CARE requires input from MULTIMODAL ACTS. TAKE GOOD CARE requires MASH-UP to learn about the space with tools of the environment. TAKE GOOD CARE requires HANDY MULTI TOOLS to react to unforeseen events. TAKE GOOD CARE is trained in EXERCISE and improved through LEARN BY MISTAKE.

Figure 30: Firefighters count their steps

SHARED ESTIMATES

Firefighters need to share information with their peers as part of the EVER-CHANGING PUZZLE*; they need numeric figures to make decisions on technical equipment. However, they lack information and do not have precise measurements.*

Therefore, firefighters need to get comfortable with numeric information, produce estimates that size the environment and can be shared.

Firefighters use numeric estimates to define the environment and share this information with colleagues.

Firefighters frequently make use of estimated dimensions of the environment that they work in. In a training mission in an apartment building, I completely lost my orientation and even did not know on which floor I was. When I asked the firefighter, who guided me, how he achieved to stay aware of our position, he told me that he had counted the steps of the staircase and kept counting the floor levels while we went up and down (Figure 30). Knowing that each step was about 20 cm high, he was even able to estimate our current height.

This concept could be observed with both French and German firefighters. After completing a mission, a firefighter reported back to the commander with description of the way that he had taken and the environment he had encountered, without vision, through MULTIMODAL ACTS. As the following excerpt shows, he nevertheless frequently uses estimated numeric values to describe the environment in its dimensions.

> OK, well, I walk this way. And at the beginning the way is pretty OK. You get down about 10 steps here … there is the first room. […] Here is a room full of stuff … seems to be a small room … you only have about 1 square meter to go on. […] And here you get to another room about 12 square meters. […] Here you get to a big room about 15 square meters. We made a round here and then made a right. There is a little recess here … clac clac … nothing there. I do not know how high this is. We make a round in this part and here is a little wall, about 40 centimeters high. Here is another room part about two by two meters and empty.

In another mission, a firefighter actively asks for numeric estimates as a means to guide his way after receiving some unclear information by the incident commander. He said:

> Here we are at the point of the kitchen door, we go right. How many meters do we go then? When do we have to turn? Tell me, this will be easier.

Firefighters also adopt numbers to describe their equipment.

As for the environment, numbers also allow firefighters to specify their equipment. When describing their equipment, numbers are frequently mentioned. Firefighters know that the lifeline has a length of 40 meters, they can easily recall the length of the different ladders, they know that a standard C hose has a length of 15 meters or that the unfolded jump cushion has a dimension of 3.5 by 3.5 meters and that it requires 60 seconds for the cushion to unfold when filled with compressed air. Also, they know the volume of extinguishing agent in their engines and that the volume increases when they produce foam by 75 to 200 times, depending on the density of the foam.

In combination, numeric values of the environment and the equipment allow understanding the limitations of equipment.

The numbers allow defining the appropriate cases in which technology is used. The length of the ladders needs to be considered. Regulations also limit the use of certain equipment by numeric values. The jump cushion, for instance, is only approved for jumps from 16 meters height. Additionally, best practices are important. Connecting multiple lifelines is possible, but firefighters stated that they could not connect more than two or three lifelines resulting in a 80 or 120 meters long line as a longer line is more difficult to handle and needs to be stretched.

At the firefighting training school, a trainer demonstrated the ability of their simulation environment to fill a basement with water in a training scenario.

> If I fill the room with water up to the top, for the intervention the team lead has to make the tactical decision: With which pump do I empty the basement? And then […] they come and want to put in a small immersion pump. Then you have to pump for ten hours. They simply have to have an idea: three meters long, four meters wide, two meters high. How much is that? How many cubic meters? How much power does which pump have? I have to use the right equipment, after all.

Again, it is a key skill to estimate the dimensions of the unknown environment in order to use appropriate tools.

Also, the estimates allow assessing the level of safety. Talking about their helmets and a new regulation that forbids aluminum as a material to shield electricity, a firefighter pointed to an accident in which a firefighter died from an electrical shock. He said there exists no material that could shield a voltage of 50KV, as it showed in that tragic case, and that therefore even regulations cannot guarantee absolute safety.

Shared numbers help to staff missions appropriately.

Based on shared estimates, commanders decide on how many units to deploy. One fire commander said:

> In an apartment like this we send one team. If it's an apartment that will exceed 150 square meters … perhaps a second team. For an apartment that goes up to 100, 120 square meters we will send one team and no more. Because communication means too much information: Who talks to whom?

Finding the appropriate number of teams is important; the commander explained that with an increased number of people also increases the chance for unclear stream of information among the many actors.

Individual practices vary here. The Cologne firefighters always try to engage an apartment with a minimum of two teams. However, the concept of using estimates to grasp the environment is commonly applied.

Shared numbers are used when giving commands.

When provided with a map that even did not feature a dedicated scale, commanders used estimated distances to give directions to a team on the frontline. To find a hidden bottle, for example, the respective commander provides directions with estimated distance.

IC	via radio	Once you're in the room, you make a right, you follow the wall, you'll make approximately two meters and you will have the entrance of a bathroom and there is a victim inside.

In this case, the firefighters were able to find the bottle without further communication.

Also, as shown in the following example, firefighters on-site directly relied on the estimated distance in the commands.

IC	via radio	When you'll find the door in front of you, you turn left and you'll arrive in the living room, you continue four meters on your left and then you turn right. Straight ahead there will be a

		wall. You should find the bottle in the middle of the room.
		The team enters a room, turns left and follows a hallway.
FF1	to FF2	three, four

Firefighters have varying levels of certainty about the information that they share and need to openly express the level of confidence or the inability to provide estimates.

In the following dialogue the firefighter was asked to provide a report after returning from a mission. The mental picture he formed during the mission, is however vague and he states this fact directly.

IC	What did you do next?
FF1	We went back to the hallway and you get to another step and … hm … also with a door. The door is open … no, is it on the other side? The door is on the level of the step and ah … we started ah … to scan this room … I could not estimate the size and then we got the signal and continued to go on.

When provided with new technology, firefighters actively ask for scales and integrate new scales and measure to their practice.

When provided with the new digital command post system, a commander argued for integrating a scale. He said: "What is missing on this map is the scale. On the other [paper] map I could easily say, go two meters." Interestingly, the paper map provided to the commander before, did not include a scale. The digital command post system however, displays the map in a three-dimensional way that differs from common maps. Also, the symbols for firefighters on the command post display were not in scale with the rest of the map.

After using the digital command post system for about 10 minutes, another commander (IC) developed a sense for the scale and gave directions to his team (FF1, FF2) that included estimated distances, as shown in the following transcript.

FF1	via radio	Found the door.

IC	via radio	So you go forward, on your left, you need to go about five meters.
		FF1, FF2 enter room R22.
FF1	via radio	I opened the door because in front of me there was a wall. I go five meters to the right. Do you copy?
IC	via radio	You continue on your left once the door is opened, on your left.
FF1	via radio	Left.
FF1	to FF2	The wall is five meters to the left.

This quick adoption of scales also was visible in the design of the signal strength feedback mechanism integrated in the mask. In the mockup mask, a LED bar with eight LEDs indicated the radio signal strength to the selected beacon. In the tests, the number of LED that light up was immediately used for communicating the signal strength among colleagues.

Dealing with numbers and different physical units is part of exercise.

In the training, beyond estimating environments and choosing the correct equipment, firefighters need to solve mathematical problems that require basic arithmetic and physic calculations. Klingsohr (2007) provides some cases and exercises that are typical in firefighting to support firefighters in their education and practice and explains concepts such as forces, acceleration, levers, volumes and pressures at the example of firefighting scenarios.

The pattern SHARED ESTIMATES gets referred to by EVER-CHANGING PUZZLE and PROCEDURES and links to MULTIMODAL ACTS and EXERCISE.

In order to receive information for the EVER-CHANGING PUZZLE, firefighters require SHARED ESTIMATES. PROCEDURES require SHARED ESTIMATES as input for making decisions.

SHARED ESTIMATES require MULTIMODAL ACTS as input to be estimated. SHARED ESTIMATES need to be trained in EXERCISE.

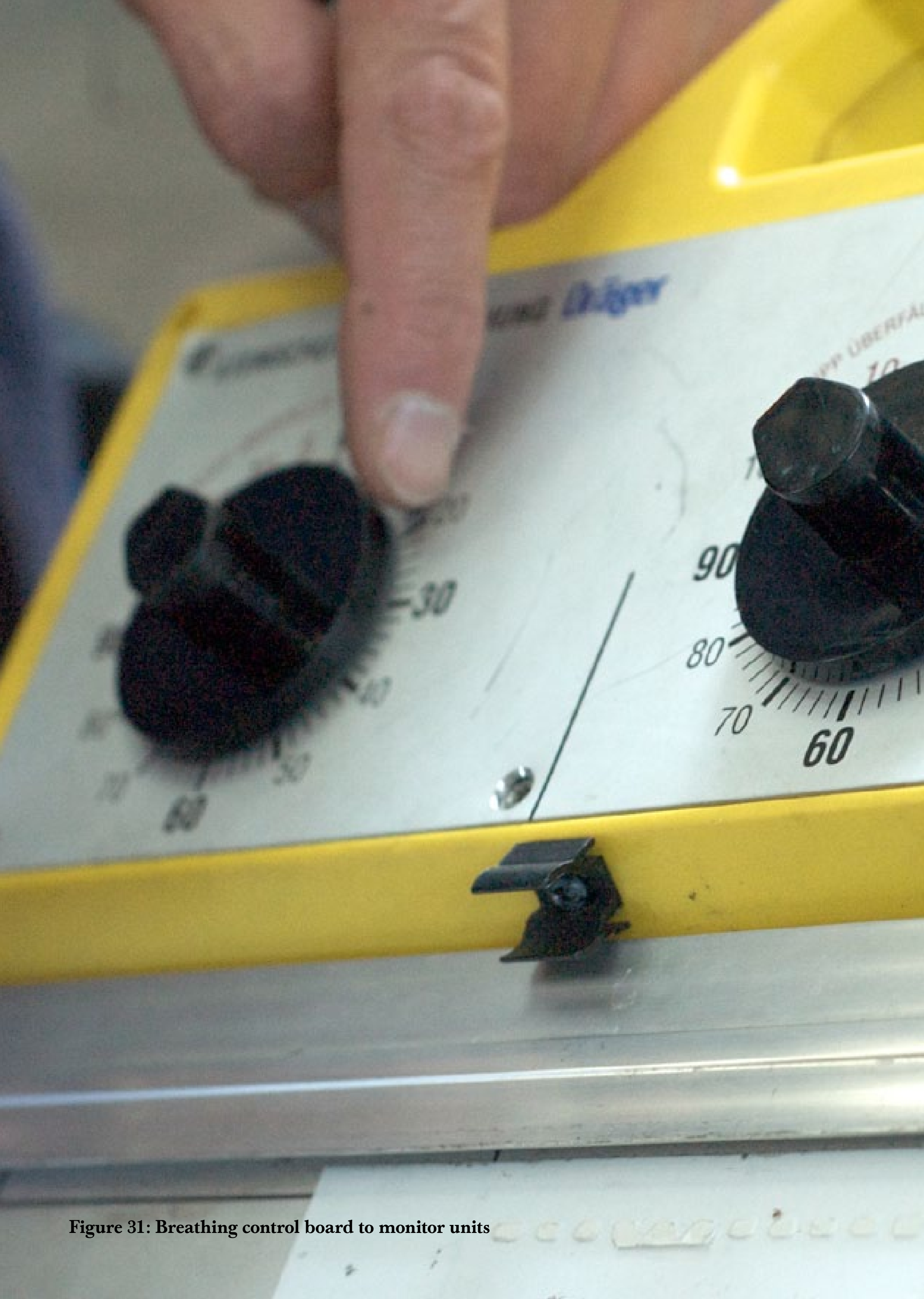

Figure 31: Breathing control board to monitor units

MONITORING

Firefighters might face situations where sudden changes and threats put them in danger and they need immediate help. Those situations need to be recognized. Especially with INDEPENDENT UNITS *it is difficult to ensure that emerging threats are identified in time.*

Therefore, firefighters monitor the operation and thereby gain an understanding of what is going on now in the context of what has happened before. More than a mere PROCEDURE, *monitoring means caring for others and fulfilling an expected obligation.*

Before a firefighter enters a building, a monitoring process is initiated.

Attached to the firefighter's breathing apparatus is a plastic tag that he inserts in a breathing control board before starting a mission. Outside the building, a firefighter is dedicated to monitor the board. He writes down the time at which the firefighter connects the breathing apparatus and the initial pressure of the compressed air cylinder. A standard bottle provides the firefighter air for about 30 minutes.

With the Parisian firefighters, before engaging the house, the group leader plugs the marks into the board and writes besides them the current time and, by adding 25 minutes, the proposed end time.

With the Cologne firefighters, the board additionally features a timer (Figure 31). After each 10 minutes the firefighter at the board requests the firefighters inside the building via radio to report their current pressure left in their bottles. The standard procedure suggests the firefighters to plan 10 minutes of air as backup when scheduling a mission. Beyond the pressure check, firefighters state that the radio call serves them as a clock as they do not bring a wristwatch to the frontline.

Movement sensors in the firefighter equipment detect crucial situations.

Monitoring also happens directly on the frontline. The Personal Alert Safety System (PASS) devices feature movement sensors attached to the breathing apparatus to detect when a firefighter faces problems. When he is no longer moving, the sensor triggers an audible alarm to inform colleagues. In the studies, firefighters could be observed moving the apparatus periodically as a means to avoid this alarm from being triggered when waiting for instructions.

Some monitoring activities are quite subtle.

When positioned near our computer system in a control room and thereby relatively far from the position close to the building where he usually stands, a commander noted that he misses the unwinding lifeline as a means to monitor the progress of the engaging team. He said:

> There is also another thing … the man who is outside who holds the lifeline … from my position, I do not see a lot … what is his progress, etc…

> that is also a point. I do not see how fast … two meters … I do not see two meters of rope passing. I do not know if it was two meters that he made.

Regarding the same issue, another firefighter noted that also the end of the 40-meter lifeline needs to be monitored. “Usually the lifeline is completely unfolded before entering […] to see the distance and be able to predict if a second needs to be quickly connected.”

Monitoring also takes place within the small units.

To ensure the integrity of their unit, firefighters frequently check if their partner is doing OK. They want to stay aware of each other’s condition and location. In introductions to the frontline work, researchers were told to frequently touch their partners’ bodies as a means to communicate their presence. At the same time, team leaders were advised to frequently check whether their teammate is still with them. In this way, firefighters are trying to be constantly aware of each other, as they need to stay close to not loose each other.

Monitoring also takes place individually, with each firefighter on the frontline.

Each firefighter tries to keep track of his location. Keeping track also helps the firefighters form a mental model of the physical space that they encounter. After coming back out of an apartment, firefighters could draw a map of the building recounting their experiences step by step. Both German and French firefighters relied on counting the steps of staircases and the floors in a building and based on that information, estimate their own position and path. One particular instance of keeping track is marking THE WAY BACK during missions inside buildings full of smoke.

Monitoring is a social process.

Knowing that there is somebody outside who monitors what is going on inside, who checks time and air pressure level and knowing that there is a partner who takes care, creates a safety net that the frontline firefighter can trust. In the heat training exercises, where the work was done facing real fire under potentially dangerous conditions, firefighters were always alerted and immediately offered help, even if their research teammate rolled the eyes just for fun when wearing a breathing mask. While researchers drew more attention and firefighters acknowledged that they were more cautious when entering hazardous training environments with novices, their frequent checks and continuous monitoring actions nevertheless showed how automatically firefighters look after each other and how deep this mutual care is rooted in their practice.

Fulfilling monitoring procedures is not only a task but also a means to look after and care for a colleague, a member of a BIG FAMILY.

Once problems are detected, firefighters send backup or call for additional support.

If problems have occurred that a frontline team cannot handle by themselves, a BACKUP TEAM is sent as support. If existing resources are exceeded, commanders will call for additional resources.

The pattern MONITORING gets referred to by EVER-CHANGING PUZZLE, PROCEDURES and INDEPENDENT UNITS and links to BIG FAMILY, BACKUP TEAM, THE WAY BACK and MULTIMODAL ACTS.

MONITORING is a specific case of PROCEDURES. INDEPENDENT UNITS require safety through MONITORING. The EVER-CHANGING PUZZLE requires constant information updates from MONITORING.

MONITORING requires a BIG FAMILY to improve mutual understanding and the interpretation of information. MONITORING within a frontline team requires MULTIMODAL ACTS. Once MONITORING has detected a critical situation it requires a BACKUP TEAM. One specific case of MONITORING in the frontline team is THE WAY BACK.

Figure 32: Firefighters after training in St. Denis, France

BIG FAMILY

In a firefighting operation with a RIGID STRUCTURE *and* INDEPENDENT UNITS, *tasks and roles have different characteristics and require different skills. It is however necessary for firefighters to work jointly on an* EVER-CHANGING PUZZLE *and to interpret their and others' situations in* MONITORING *to make mutual sense of the shared information.*

Therefore, firefighters form a close team in which seniors and subordinates know each other well, as a big family. They train people for senior positions but ensure that everybody is aware what the others are doing and that they have empathy for each other.

The firehouse is a second home for firefighters.

Firefighters work in shifts that are much longer than typical office workdays. Being together day and night establishes a deep social bond between firefighters. Firefighters frequently mention that their relation goes beyond the professional work they have to perform (Figure 32). The firehouse becomes a second home:

> When we are done, I will tell the guys 'let's go home'. That might sound a bit strange but, after all, we spend a large part of our life together at the station.

An incident commander joked about knowing a lot about all of his subordinates. He emphasized that the private lives of firefighters are mostly opened up, almost in an intimate way. "We shower together", he said and emphasized that the nature of the job is fairly different from other office environments, simply from being together for longer periods of time.

Other firefighters told stories about how they play jokes on each other and that sometimes those tricks would play pranks on a firefighter. After telling several anecdotes, a firefighter said:

> You might think now we're a bit crazy. But you have to know: We can have a lot of fun but when it gets serious, we can work very hard. I know I can count on everybody when it gets serious.

Their connection extends beyond the firehouse.

Several firefighters reported, that they help each other outside their regular work. As German professional firefighters have to hold an education as a craftsman before applying to become a firefighter, they explained that they have electricians, roofers, carpenters, mechanics and painters among their peers and could support each other in different tasks in dealing with their houses or cars.

An incident commander, for his subordinated team, is not only a superior firefighter or commander, but also an advisor for issues of daily life. "I have many jobs here, sometimes I act as marriage counselor", stated an incident commander.

This social bond at the firehouse crosses hierarchic levels.

In the workshops, high-ranked commander often took a hands-on approach. They quickly changed their dress uniform to protective clothing, and were eager to try things themselves. While these commanders are usually working in offices only, they are still responsible for taking the command of large incidents.

An incident commander reported about sometimes taking himself the exercises that are required to work with a breathing apparatus, even though he himself would never enter a building.

Some other high-ranked firefighters, who, by their job, do not come to see fire, as they work in education or administration, still choose firefighting as their free-time activity and they join volunteer firefighters in their place of residence.

Also, extra activities are performed together in some cases. A commander, for example, joined his subordinates in preparing and taking part at the New York City Marathon.

While this connection does not seem to go all up to the top levels, and lower level firefighters sometimes referred to high-level commanders as the ones working on the 'plush-level', in the higher floors of the buildings that have carpets, this distance does not exist with the people directly involved in the work at the frontline.

The pattern BIG FAMILY gets referred to by MONITORING, EVER-CHANGING PUZZLE, INDEPENDENT UNITS and RIGID STRUCTURE.

To form the social bond of RIGID STRUCTURE requires a BIG FAMILY. MONITORING requires a BIG FAMILY to improve mutual understanding and the interpretation of information. INDEPENDENT UNITS rely on their comrades as part of the BIG FAMILY. For a greater mutual understanding and the interpretation of each other's information, EVER-CHANGING PUZZLE also relies on BIG FAMILY.

Figure 33: A backup team waits outside

BACKUP TEAM

As INDEPENDENT UNITS, *firefighters might face situations out of which they cannot lift themselves. In these cases of emergency they need immediate outside help. Other colleagues, however, might be busy with their own tasks and therefore could not be available for quick support.*

Therefore, firefighters have backup teams on standby that are solely delegated to provide support to INDEPENDENT UNITS *who are in trouble on the frontline.*

The backup team is the standard means to provide support to the teams working on the frontline.

In all the observed EXERCISES, a backup team was appointed, disregarding if the backup team was playing an active role in the particular training or not. While other parts of the work such as the use of the breathing apparatus and control were sometime skipped given the safe training environments, the back up team was always appointed. All the accident reports show that the backup team plays a crucial role in supporting the teams on site.

The backup team is equipped with the same protective gear and already wearing the breathing apparatus to be able to engage immediately (Figure 33). In Cologne, the backup team carries a special bag that holds a rescue cloth and a rescue strap to apply different techniques for recovering firefighters in danger.

In German regulations, the backup team is mentioned as mandatory for intervention where firefighters use breathing control apparatuses. Incident commanders are responsible for always ensuring the availability of a backup team and allocate multiple teams, if necessary. (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe 2005: 17) Additionally, the regulations make the backup team responsible to ensure a permanent radio connection to the frontline and engage a building until a radio connection to the frontline can be made again. (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe 2005: 11)

The backup team relies on the path marked by the frontline team and follows their traces.

After engaging on a rescue mission, the backup team will try to follow the path (THE WAY BACK) that the team in need has followed and, as in standard mission, will read from the cues produced by their comrades (MULTIMODAL ACTS).

The pattern BACKUP TEAM gets referred to by MONITORING, INDEPENDENT UNITS and RIGID STRUCTURE and links to MULTIMODAL ACTS, THE WAY BACK and EXERCISE.

The BACKUP TEAM is a specific part of the RIGID STRUCTURE and is required for the safety of INDEPENDENT UNITS. MONITORING requires the BACKUP TEAM when emergency situations have been identified.

On rescue missions, the BACKUP TEAM requires MULTIMODAL ACTS and THE WAY BACK to find their comrades in need. Firefighter need to train rescue operations using the BACKUP TEAM in EXERCISE.

Figure 34: The lifeline marks the way back

THE WAY BACK

When engaging an operation in an unknown, dangerous and dynamic environment, firefighters might face difficulties they cannot solve in the limited time they have.

Therefore, firefighters always make sure to have way to return to a safe place. They therefore mark the way that they follow as a path that they know to be safe. They usually use this path to return. This path also works as a way for a backup team to find the teammates who need help.

Firefighters actively build a return path using fire hoses or ropes.

When engaging an unsafe building structure, firefighters use different tools to build a path that brings them back to the place where they left the safe area.

When engaging with a fire hose, the hose builds the way back. Hoses used inside buildings are 15 meters long. The hose pieces are connected together by metal couplings. These couplings can cause problems if they get stuck, especially in doors or around corners. To deal with this, firefighters carry a number of wooden wedges that they put under doors to keep them open.

When engaging without a fire hose, they use a rope. The rope builds the way back and is between 30 and 40 m long. The rope has to be stretched before the team can return (Figure 34). Ropes can also be used to create more complex networks of paths during the course of an intervention. French firefighters call the rope that connects them to the outside 'commande' as a command that guides them, English firefighters call it 'lifeline' and in German the tool is called 'Rettungsleine', which literally translates to 'rescue rope', all pointing to the vital quality of the artifact. The rope can also be used as an extension of a hose or as a physical link between two firefighters in a team; it becomes a HANDY MULTI TOOL.

Even though these tools are not without problems, they provide a tangible way of returning that is considered safe and seems to be without alternative.

When provided with the digital command post, firefighters referred to the lifeline as a safe means to return, and ignored the more complex commands given by the commander, as the following dialogue shows:

IC	via radio	You go back on your left, you go out, once you have arrived at the entrance of the room, you make a right and you come back to the room, the first point of departure.
FF1	via radio	OK, we will follow the lifeline. It will be safe. Tell them to stretch the lifeline.

Nevertheless, in some missions with the Parisian firefighters, a key issue and the cause for the major breakdowns during the exercise were problems caused by the ropes of the teams that got entangled in furniture. Also, when multiple teams entered an apartment, they faced the problem of intertwined lifelines. Problems in stretching the lifeline, as a consequence, required firefighters to deal with the problem of the rope for several minutes.

For the hose, German firefighters reported that they sometimes have problem in finding the direction of the hose once they had lost their orientation, as hoses going in circles are difficult to be followed. As the accident report by Bürger et al. (2006) shows, hoses, when conducting a foam water mix, can also overheat, explode and make the return impossible.

Nevertheless, there are currently no safer alternatives to mark the way back as the physical links provided by ropes or hoses that can create a path that can be seen and felt (MULTIMODAL ACTS).

Beyond these tools, firefighters follow PROCEDURES to ensure their return path.

When engaging a building, firefighters need to decide which way to take so that they can ensure that they scan buildings in full. At the Cologne firefighters, the 'right hand rule' should support the navigation indoors; they always follow the wall to their right. This rule also supports to guess behavior that a back up team can use as input when trying to help and find missing colleagues. When searching for their colleagues, firefighters often referred to that rule, as an expected behavior, and also actively mentioned the cases in which the rule could not be followed.

Along their way, firefighters additionally mark rooms with chalk or wax pens and thereby leave tags that support them on their way back.

The way back is used by other firefighters to build upon their work and for rescue missions.

The path created by the team that engages first and can be used by consecutive teams, as the first team can leave the path intact when returning.

In their reconnaissance missions with handovers between different teams, the team lead of the second team removed the lifeline of the first team from the doorknob and used it to continue the reconnaissance. Also, the fire hose was referred to as a means to continue the work at the place where previous teams left it.

For cases of emergency the BACKUP TEAM relies on the path built by the team to find their comrades. The end of the built path is the beginning of the rescue mission. Should the firefighter have lost the path, it is likely that he can be found nearby.

The pattern THE WAY BACK gets referred to by BACKUP TEAM, MONITORING, PROCEDURES and INDEPENDENT UNITS and links to MULTIMODAL ACTS, MASH-UP and HANDY MULTI TOOLS.

THE WAY BACK is a specific case of PROCEDURES that provides safety for INDEPENDENT UNITS. THE WAY BACK is also a specific case of MONITORING in the frontline team. A BACKUP TEAM requires THE WAY BACK to find the comrades in need.

THE WAY BACK requires MASH-UP for orientation in reference to the environment. THE WAY BACK requires HANDY MULTI TOOLS that support orientation in unknown spaces.

Figure 35: Firefighter on the frontline in a training environment

MULTIMODAL ACTS

Working in rooms full of smoke, firefighters have difficulties in grasping the environment visually.

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.

Firefighters make use of a lot of multimodal indications in their work.

For some exercises, firefighters had to find water bottles, marking the locations of symbolized victims. In these cases, the training environment did not simulate real world conditions; instead, firefighters engaged in normal apartments and their masks were simply covered using sandwich paper.

Experiencing these changes to the practice, firefighters pointed out that this experience is quite different from real interventions where the victim itself and the environment provides multi sensory inputs that become a reference for orientation and a means to understand the overall context.

In an interview that was conducted directly after a the team returned from their mission a firefighter reported:

> If we do a reconnaissance of fire, we will feel the heat, the crackling of the flames, so it can help us while here there is nothing. A bottle of water does not speak. It does not get warm. And a victim can always whine, can still scream 'help, help' and will provide orientation. One listens. Reconnaissance is done this way. And also, it is also a little bit a special feeling. And then we still, even if it is in the smoke, we can still see 50 centimeters minimum. Even if the smoke is opaque, we will see 2 meters, such as one gets … we will see what happens, we will see that it is a wall, if there is a door, or something like that. Here, there were only two things important, touch and the voice of the commander.

In comparison to the tactile modality and the audible commands given by the commander, a firefighting mission gets support by audible, visual and temperature cues.

Another firefighter put it this way:

> As I have just said, it is better in a real intervention because you may orientate yourself in relation to smoke, heat and noise. You can always hear a victim ... If you hear a victim whining, we can go get her. But a bottle of water does not speak; it does not get warm.

Firefighters benefit from tactile input.

Navigating their way in buildings full of smoke, firefighters feel their ways using their whole body. As they usually crawl on the floor to avoid the heat in the higher regions in a room, their standard way of moving is already a tactile experience that includes legs and arms (Figure 35). By feeling the environment around them, they try to understand the location they are at.

Touching each other is a means for monitoring. Firefighters check if their teammate is still with them and doing OK. Also, while crawling their way, they frequently provide each other a helping hand.

Firefighters benefit from audible input.

As the firefighters said in the above quote, the fire itself is an audible experience that serves as a reference. “One listens”, as the firefighter put it.

Another source of sounds are victims calling for help or whining. This aspect of firefighting is also simulated in the training environment in Münster, Germany, where speakers positioned close to dummy victims make them call for help. In this environment, firefighters were also observed to actively call for the victims. In trainings firefighters actively asked me to call out loudly “This is the firefighters, is there anybody here?” in order to find potential victims.

Sounds are also triggered to warn firefighters when they face a problem. Audible alarms are triggered when the air pressure in the compressed air cylinder sinks below a defined threshold, telling the firefighter that he will run out of air soon. Such alarms also help to tell other firefighters what is going on and where their colleague is located. As with the air pressure warnings, the Personal Alert Safety Systems (PASS) feature movement sensors attached to the breathing apparatus to detect when a firefighter is no longer moving and also triggers an audible alarm.

In a very special case of audible support a firefighter was able to find a missing colleague by listening and locating the sounds coming from his radio. The incident report reconstructs the events:

> Due to a hint via radio the team moves in the direction of the south end of the staircase. There they hear sounds of the radio of the team lead of team Geismar 2. Now they count over radio, the team continues to orientate himself by the noises and finds the firefighter in danger. They carry him to the south entrance. (Moravec et al. 2007: 19-20)

Later, the incident report directly shows the practice developed as an alternative to PASS devices:

> The firefighter, who had the accident, was not equipped with a PASS device but he was equipped with a 2-meter handheld radio that was operational during the search mission. As a replacement for the missing PASS device, radio silence was ordered on the channel that was selected on the device and on another radio device a sound signal was produced by counting. Thereby, the missing firefighter comrade could be finally located. (Moravec et al. 2007: 40)

Firefighters benefit from thermal input.

As indicated in the quotes at the beginning of this pattern, feeling the temperature is important.

The fire produces a great amount of heat that can provide orientation. Firefighters said that new protective clothing that shields the heat might prevent them from making use of temperature sensing. New hoods also cover the ears that before were a sensor for the temperature. Firefighters noted that a melting helm visor is a clear indication that it is too hot and time to return.

As a means to feel the temperature, firefighters, at some points during an intervention, take off their gloves, for example to feel the temperature of a door before opening it as a hot door might signify the danger of a flashover explosion. While taking off a glove, firefighters must prevent hot air from getting inside the glove, in order to avoid burns.

Beyond the heat caused by fire, firefighters also mention the temperature of a body that can help to identify a victim.

Firefighters benefit from what they see.

Despite a work environment that greatly limits sight, firefighter frequently mention that they can still see in burning environments.

In a room, a firefighter with his masks covered, describes his impression of large window front that he identifies by the amount of light that he sees and states: “I have reached the end of the room on the left side. It’s like day. There must be a window or so.”

Firefighters however also indicate that they can see much more in burning buildings than with their masks covered the exercises. Explaining why the walls can guide him even though there is furniture, a firefighter noted:

> It is correct that with cabinets, something higher, there was a gap between the walls. But I do not think it is that different. The worst case is white smoke. With the white paper we do not really see much. But [in case of white smoke] you can see a few centimeters and distinguish a cabinet from a wall.

With artificial white smoke in other training exercises, firefighters reported that in most cases thermal effects cause dark smoke to stay in the higher regions of the apartment and that usually an area of 0.5 to 1 meters at the bottom of the room stays smoke free, allowing them to understand the environment visually.

Firefighters train multi-sensual aspects of the work.

In addition to the training in normal environments with simulated limited sight that makes them focus on experiencing a building by touch it, other EXERCISES specifically focus on the work in hot environments with real fire. Additionally, as experienced at the Fire Service Institute in Münster, training facilities make use of sounds of fire and victims to train the audible experience.

The pattern MULTIMODAL ACTS gets referred to by BACKUP TEAM, THE WAY BACK, SHARED ESTIMATES, MONITORING, EVER-CHANGING PUZZLE and TAKE GOOD CARE and links to MASH-UP and EXERCISE.

On rescue missions, the BACKUP TEAM requires MULTIMODAL ACTS to find the comrades in need. Orientation for finding THE WAY BACK requires MULTIMODAL ACTS. SHARED ESTIMATES require MULTIMODAL ACTS as input to be estimated. MONITORING within a frontline team requires MULTIMODAL ACTS to learn about the status of comrades and feel the environment. In order to receive information for the EVER-CHANGING PUZZLE, firefighters require MULTIMODAL ACTS. TAKE GOOD CARE requires input from MULTIMODAL ACTS.

MULTIMODAL ACTS require MASH-UP as new sensory input. For MULTIMODAL ACTS, all the senses are required to be trained in EXERCISE.

Figure 36: A firefighter uses a bottle he found on-site to extend his arm

MASH-UP

While the situation on-site is difficult to predict and firefighters need to TAKE GOOD CARE, INDEPENDENT UNITS *are only able to carry so much equipment to the frontline; each additional tool has to be lifted by an already heavily loaded firefighter.*

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 tools.

Firefighters make use of furniture as a temporary means to scan the environment.

While furniture may block the way of a firefighter, beyond simply moving the furniture out of their way, firefighters use furniture to feel the environment around them by pushing it in different directions to look for other objects and walls and to enlarge the radius of scanning the environment. Furniture that is relatively easy to move, such as chairs, stools and small tables thereby can become a means to extend the range for scanning the environment. While scanning an apartment, firefighters in the experiments also threw chairs across the rooms. Thereby, they also got some audible feedback of the contents of the room.

Sometimes, things found on-site are adopted as tools.

In an experiment where water bottles became symbols for victims and marked places that firefighters should find, firefighters made use of the bottles as an extension of their arm that they kept during the entire intervention to scan the apartment (Figure 36).

The environment becomes a reference system.

In limited visibility conditions, firefighters navigate using the existing infrastructure such as walls and doors. These reference points help them to create a mental model of the environment. During debrief, their descriptions referred to existing infrastructure. Simple elements such as doors, corners and windows become reference points.

The environment is mixed with existing tools.

The tools that firefighters bring to the frontline (HANDY MULTI TOOLS) can be mixed with the environment. Firefighters use for instance the lifeline as a retreat path by fixing it to door handle or other fixing possibilities. Chalk or wax pens are used to mark places and to store information on-site. Firefighters leave markings on the door to indicate if they have entered a room or if a room has been successfully scanned. Such mash-ups are visual and tangible means of support, they allow for MULTIMODAL ACTS.

Outside of the incident site, fire engines are used as reference points. With the Parisian firefighters, in large incidents the teams also include an especially trained firefighter that can draw ad-hoc maps and diagrams to support the strategic reasoning. These maps consist of a mixture of reference points from the existing site, fire and smoke, fire trucks and other equipment.

The pattern MASH-UP gets referred to by MULTIMODAL ACTS, TAKE GOOD CARE, THE WAY BACK and INDEPENDENT UNITS and links to HANDY MULTI TOOLS and EXERCISE.

Given their limited resources INDEPENDENT UNITS require MASH-UP. TAKE GOOD CARE requires MASH-UP to learn about the space with tools of the environment. MULTIMODAL ACTS require MASH-UP as new sensory input. THE WAY BACK requires MASH-UP for orientation in unknown spaces.

MASH-UP requires HANDY MULTI TOOLS to combine the tools with the environment. MASH-UP requires EXERCISE to train firefighters in using the environment.

Figure 37: Personal tools of a firefighter

HANDY MULTI TOOLS

Firefighters frequently face problems that require special tools. Physical constraints and time constraints make it impossible to have all the required tools at hand as INDEPENDENT UNITS *can neither lift additional load nor have the time and energy to go back to the engine, 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. Tools are designed open for new uses and can be combined with the environment.

For a firefighter, there is only so much time for performing on-site actions. Returning to the engine to get additional equipment is usually not an option.

A standard firefighting mission inside a building on the frontline lasts 30 minutes, the time for which air is available. During that period, the firefighter has to move to the frontline, perform his tasks and return. Usually, this time frame leaves no option to return to an engine during a mission.

With the existing tools, firefighters are heavily equipped.

The standard protection gear of a firefighter weighs about 25 kilograms. It comprises the compressed air cylinder with about 15 kilograms and 10 kilograms for the rest for protective clothing, the helmet, mask, etc.

In addition to that protective gear and dependent on the role that they are assigned, firefighters may carry the nozzle and hoses, a flashlight, an ax, a rope, wooden wedges, wax pens or chalk, a rescue hood for victims, radio, an infrared camera and a variety of small tools such as knives, scissors, screwdrivers, pH paper, oil detection paper, additional plastic gloves for rescue services and gloves for cleaning up after an incident.

Most standard tools are open for different uses and thus can be used by firefighters for different purposes; they allow for improvisation.

The fire nozzle is designed for water protection and control at the same time. It is a heavy, gun-like artifact that provides a steady stream of water with variable flow and aperture. It provides a moving ring to control the width of the water stream and a large handle to control the amount of flowing of water. Water spouts out when this handle is pulled back. This is designed in this way so that when an explosion occurs, the movement of the firefighter automatically opens the nozzle, shielding the firefighter with water.

Water in itself is multi purpose tool, too. Water is used to extinguish fire, to provide protection, to move smoke and as a means to cool the temperature in a room and to sense the temperature. On the frontline, firefighters use small amounts of water to cool down the hot air at the ceiling before entering rooms. This requires a delicate control of flow and aperture, as firefighters must prevent producing too much steam, which works as a heat conductor and can quickly raise the temperature of the environment. Also, they learn of a high temperature from water that evaporates immediately.

The fire hoses are not only used to convey water, but also serve as a tool to create a path from the point of entrance to the frontline; it marks **THE WAY BACK**. In trainings, firefighters also used the hose as a tool to scan large rooms for victims. In a scenario where a person was missing in a parking garage, two firefighters clamped the hose over a distance of about 3 meters between them and thereby could scan a large area in a short period of time.

Firefighters also carry a 30 to 40 m long rope, the so-called lifeline. This rope can serve as an alternative to the hose for marking the retreat path in missions where fire hoses are not used. It can also be used when a large room has to be scanned and firefighters have to leave the walls. In these cases, the lifeline connects two teammates, one staying in a fixed place at the wall and the other scanning the room in circles.

Carried by the last person in a team, the ax serves as a means to break into closed windows and doors but also allows extending the firefighter's arm. While scanning rooms, the wooden shaft is used to feel the environment. In this way, the firefighter can search for victims under beds and behind other obstacles.

The infrared camera, often the only digital artifact on the frontline, is also used for different purposes. Besides the direct support in fighting fire by detecting the origin of a fire or finding fire pockets, the infrared camera supports the search for victims both in fire as well as in water; it supports the work at night, the analysis of fill levels and the work with electric installations. Training documents for the infrared camera reveal that such alternative usages are part of standard **EXERCISE**.

Small tools are in some cases designed by the firefighters themselves, even though that might cause legal problems in cases of accidents related to those tools, as they are not officially approved for the use on the frontline. Seat belts or wooden wedges are for instance built by firefighters themselves in the warehouse of the fire station. In describing their tools, firefighters mention alternative uses. Short cut safety belts from cars, for instance, were described to be useful as a means to fix hoses to handrails as well as supporting dragging a person (Figure 37). Wedges to keep doors open and thereby prevent the metal couplings of the fire hose from getting stuck were designed to fit both doors with large and small door clearances at the same time by designing wedge shapes in two different dimensions.

Finding such smart solutions is valued among firefighters; they present their creativity to their teammates. “You don’t earn enough,” joked a firefighter when he saw the double side wedges of his colleague. These personal tools represent personal experience; they are the result of LEARN BY MISTAKE on an individual level.

Firefighters know their equipment well. For the more complex devices, learning the inner workings is part of exercise.

Firefighters know the details of the inner functioning of both the more simple as well as the complex devices.

Explaining the functioning of a breathing apparatus, firefighters (FF1, FF2) explained to me (SD):

FF1	Principally, all breathing apparatuses are the same. They have a bottle, a pressure reducer, a medium-pressure cable, a high-pressure cable. They have a barometer and a lung regulator, and that is the same for all devices.
SD	And are they compatible to all … the masks are probably all the same for all?
FF1	No, red [marked mask] is over-pressure.
FF2	Take a look at the new technology. [pointing to a novel breathing device]
FF1	Yes. One cable through which both cables are routed.
FF2	They go to the pressure reducer. You can see the pressure reducer here, there are two cables leaving. There is the high-pressure cable and the cable to the lung regulator and then, in the meantime, we have both cables routed in one cable.

Training materials for the infrared camera introduce basic physic principles. Heat radiation, visible and non-visible wavelengths and the interaction of electro magnetic waves with the smoke explain the fundamental principles of the device.

The pattern HANDY MULTI TOOLS gets referred to by MASH-UP, THE WAY BACK, TAKE GOOD CARE and INDEPENDENT UNITS and links to EXERCISE and LEARN BY MISTAKE.

The limited resources of INDEPENDENT UNITS require HANDY MULTI TOOLS. MASH-UP requires HANDY MULTI TOOLS to allow the combination of tools with the environment. Finding the THE WAY BACK requires HANDY MULTI TOOLS that support navigation. TAKE GOOD CARE requires HANDY MULTI TOOLS to react to unforeseen events.

HANDY MULTI TOOLS require EXERCISE to train the firefighter in using the tools for different purposes. HANDY MULTI TOOLS require LEARN BY MISTAKE as input for new functionality and to integrate experience.

Figure 38: Heat container exercise

EXERCISE

Even firefighters do not fight fire all the time. Serious fires are rare. Firefighting missions are one-shot operations, as failures in these interventions can cost lives.

Therefore, firefighters need to train their work over and over again. Thereby they have opportunities to exercise the different aspects of firefighting work practice. Exercises are designed in ways to both include standard procedures and expected exceptions.

Exercise is central to the everyday life of firefighters.

Dedicated facilities and the different kinds of exercises performed over and over again, show the importance of training in firefighting. As a trainer of a firefighting school stated, a firefighter immediately needs to act when he is woken up at 3 AM in the morning.

Firefighters exercise the physical, procedural, mental and social aspects of firefighting work.

Special facilities focus on the physical burdens that a firefighting operation causes and require firefighters to work in conditions close to those in real burning buildings (Figure 38). Fitness tests with breathing apparatuses should ensure that a firefighter could withstand the harsh conditions and work with limited air resources.

Other exercises focus on procedures, the application of tactics or how to deal with equipment. For those exercises, the physical environment may not necessarily reflect conditions on-site. In these exercises firefighters are confronted with a relatively high level of stress and need to handle difficult situations in collaboration with their teammates.

Exercise greatly relies on learning by mistake.

As a consequence of the importance of exercise, a frequent question in accident reports is how to improve exercise so that similar accidents can be prevented in the future.

Missing training makes technology unusable.

When introducing radios and the digital command post to the firefighters, missing training on how to handle the devices, hindered them considerably in performing a mission.

With the French firefighter, PROCEDURES how to handle radio traffic had not been established and firefighters had not received training on the devices. Studies with German firefighters, however, show that radio devices are very supportive in practice when previously trained.

The pattern EXERCISE gets referred to by HANDY MULTI TOOLS, MASH-UP, MULTIMODAL ACTS, BACKUP TEAM, SHARED ESTIMATES, TAKE GOOD CARE and PROCEDURES and links to LEARN BY MISTAKE.

HANDY MULTI TOOLS, MULTIMODAL ACTS, MASH-UP, BACKUP TEAM, SHARED ESTIMATES, TAKE GOOD CARE and PROCEDURES require EXERCISE as firefighters need to be trained these patterns for real interventions.

EXERCISE requires LEARN BY MISTAKE to improve training and prevent accidents from happening again.

Figure 39: Firefighting memorial in Boston, MA

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 identify the weak spots in the existing practice. They use the analysis of failures as a way to reflect on existing procedures and improve them, respectively. Firefighters prevent future accidents by learning from mistakes made in the past.

Past accidents are held present.

When talking about dangerous situations or things that might go wrong, firefighters refer to past accidents. In the cases of accidents in which a firefighters' life was lost, firefighters know what has happened to their colleagues, and also recall the names of the firefighters who died in action. Monuments, whether they are a physical (Figure 39) or digital (Wietersheim 2008), hold past accidents present. The website of the German firefighter counseling lists firefighters killed in action and provides a brief description of the incident.

Detailed analysis is a means to reflect on existing practice.

Accidents are investigated in detail. Detailed reports, usually created by a team of independent firefighting experts, reconstruct the incident. Recent examples for those reports can be found in Maurer et al. (1996), Bürger et al. (2006), Fricke (2009), Moravec et al. (2007) or Steingröver (2007).

The central mission of these reports is to identify the cause or the causal chain, to understand if the accident could have been prevented with existing procedures and tools or if the accident reveals the need for a change of the existing procedures. Moravec et al. (2007: 5) describe the central question that the investigation should answer:

> What was the cause of the accident? Would the accident be preventable? Could the firefighter who had the accident been rescued? Do we have to draw consequences for training, deployment and tools?

And Fricke (2009: 2) underlines: "This final report supports the continued enhancement of the training procedures of the firefighters of the city of Bad Harzburg."

Firefighters share accidents and near-accidents online.

Besides investigations by official committees, firefighting online communities publish records of frontline practice (e.g. (Feuerwehr Forum 2010, Firefighter Close Calls 2010b)). These reports provide accounts of accidents or cases in which accidents were likely to occur. The following example presents a near-accident in a structural fire through a flashover, a known phenomena when simultaneously all combustible material ignites in an enclosed area.

> On September 29, 2010. We were alerted bringing in several stations. Upon arrival of first engine smoke was showing from the front of store. My unit was second in and advised to make entry in the rear myself and two others forced entry and encountered heavy smoke and a lot of heat. Once entry was made it was about a minute after I saw fire come from a corner in the room. Before I could turn to put water on the fire the room had flashed over and had knocked the two behind me out of the building which was about 6 feet. After being dazed I came out and no injuries occurred. LESSONS LEARNED: Read smoke. We all need to slow down take a breath and check your surroundings. (Firefighter Close Calls 2010d)

Besides such reminders of known issues, firefighters also report about the difficulties in reading the environment that they faced to help other in the interpretation of comparable events.

> Wednesday, December 15, 2010. We were dispatched for reported construction material on fire in a parking lot at 01:41, by a third party caller. This call seemed a bit out of the ordinary due to the location, time of day, and who generated the call. En-route we noticed a small column of smoke from that area. We arrived […]. What we found was a midsized enclosed cargo type trailer fully involved. The length from the road to the back of the parking area was approx 500'. […] The side of the trailer listed the company information; the company was a mobile radiant ground heating system. With the knowledge that radiant heating systems use some type of a boiler system we were aware of the potential hazard of a pressurized vessel. Our decision was to use the deck gun to knock down the blunt of the fire. We then stretched our trash line (1 ¾) to the trailer, used our bolt cutter to cut the lock and finished knocking down the remaining fire. We noticed a large hot water tank and a large reel line of radiant tubing. We also noticed the tubing and electric cords exiting the trailer going into the building. We had a prominent hissing sound which was getting louder. We figured this sound to be the relief valve on the hot water tank. All of this was happening in a short time, 1-2 minutes at most. Suddenly, the trailer flashed back into a ball of fire from inside the trailer. We exited the area, backed the engine around the corner of the brick building, made sure all others evacuated the area, and upgraded the alarm to a structural response. We choose to let the fire burn out. It was not known what exactly was in the trailer but we surmised it was most likely a flammable

> compressed gas. […] After the fire burnt out (2 hours) we investigated the fire. What we found was a series of 5-100# propane tanks that had relieved as the hoses connecting the tanks in series had burnt through. This allowed the gas to free flow which then re-ignited. Our first thought was that the hissing sound was the relief valves, we now believe it was the burnt through hoses. LESSONS LEARNED: […] Approach suspicious fires with caution. Use the resources available, in this case the type of company this was. It was pasted all over the side but not once were we aware that large volumes of compressed flammable gases were stored inside. Follow that "gut" instinct. We felt something suspicious from the start. Hold to the risk vs. benefit theory; we had a brick building next to this trailer, no life safety and with the consideration of a BLEVE [boiling liquid expanding vapor explosion] we used defensive measures. (Firefighter Close Calls 2010c)

Firefighters also report about interaction with the public. In a particular incident, for example, a neighbor called the firefighters after hearing a smoke detector sound in another apartment. To their surprise, the occupant of the apartment confronted the engaging firefighters with a gun.

> Upon initial entrance and during the search, mask crew was verbalizing their presence in hopes of hearing a response from the occupant. The crew made it about half way down the hallway when the back bedroom opened and there was the occupant exiting the bedroom with a shot gun pointed at the crew. The outcome of this situation was positive. The occupant was extremely hard of hearing and did not hear the detector sounding in the hallway. He did hear voices coming down his hallway and assumed he had burglars in the house. Fortunately the occupant identified the fully donned crew as firefighters and any mishap was avoided. The occupant was very apologetic and was very grateful for his neighbors alertness and the crew that escorted him to safety. I do believe we are washing 4 sets of soiled turnouts today. Simply a lesson for crews to continually identify yourselves and be aware of unexpected conditions. (Firefighter Close Calls 2010e)

Other reports show that firefighters look at their environment and envision accidents that could happen, as already detailed in TAKE GOOD CARE (Firefighter Close Calls 2010a).

Practices are changed following accidents.

In an accident in 1996 a firefighter lost his life as he was caught up in his lifeline. Besides other consequences, as a direct result of this incident, firefighters are advised to carry a knife that can be used with gloves to free themselves from the rope if necessary (Maurer et al. 1996: 20). In this example, Maurer et al. note that other firefighters in Germany already apply this practice and they suggest adopting this strategy also for the firefighters of Cologne. Additionally, the report suggest changes for the long term that include the update of national standards that define the requirements and for the rope (Maurer et al. 1996: 12).

The pattern LEARN BY MISTAKE gets referred to by EXERCISE, HANDY MULTI TOOLS, TAKE GOOD CARE and PROCEDURES.

EXERCISE requires LEARN BY MISTAKE to improve training and to prevent accidents from happening again. PROCEDURES require LEARN BY MISTAKE to identify weaknesses. HANDY MULTI TOOLS require LEARN BY MISTAKE as input for new functionality and to integrate experience in tools. TAKE GOOD CARE requires LEARN BY MISTAKE to build awareness of unforeseen situations.

6 Informing Design

The emerging understanding of the frontline practice, as described in the pattern language, directly impacted the design of a navigation support system for frontline firefighters. The overall pattern language, when introduced to developers in a workshop and applied during follow-up interviews, allowed to reflectively discuss technology proposals that target frontline firefighters.

6.1 A Navigation Support System

Two research projects, focused on building a novel navigation support system for frontline firefighters, present a case, how a technology concept can be aligned with the existing configuration on the frontline as described by the pattern language.

As previously mentioned, this research has been part of two design project aimed at building a navigation system for frontline firefighters. While the pattern language evolved, the design of the navigation system was an ongoing, parallel process. This approach closely follows the action research framework and allowed to learn about the practice from changes posed by the introduced artifacts.

In the previous project with the Parisian firefighters, following a first vision, a Digital Command Post System allowed the commander to guide frontline firefighters from outside.

In the landmarke project, with the firefighters of Cologne, Germany, this concept was revised. The new design took a number of patterns as core concepts and paid attention to the existing practice and the overall configuration that is described in the pattern language.

In retrospective, the evolution of the design concept in the two projects can be analyzed using the pattern language. The pattern language allows understanding the evolution of the envisioned design concepts and explains the differences of the two main concepts that can be distinguished.

In the beginning, the research started by focusing on digital means to support frontline firefighters on THE WAY BACK. Inspired by the lifeline, the rope that firefighters use to connect to the outside, and 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 40).

In the first vision, beacons, automatically dropped by the firefighter on his way, should built an ad-hoc network and sense their relative position. On THE WAY BACK, firefighters would make use of this sensor network by following the directional information, automatically calculated and shown

Figure 40: Navigation concept based on sensor beacons

on a head-mounted display (Figure 41). Also, the system should disclose the firefighters' positions to the commander (Figure 42).

The 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 commanders 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 trust as a member of the BIG FAMILY. Navigation is 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: 191) and thereby decided to build on and not to change the existing practice and directly support INDEPENDENT UNITS in their autonomy, as INDEPENDENT UNITS make the RIGID STRUCTURE agile and are a crucial element to achieve FLUID ORDER.

Figure 41: Head mounted display guiding the way back

Based on this chosen approach we revised the existing concept and proposed a new design.

In the new concept, firefighters deploy beacons manually and use them to mark spots in the environment as new points of references, landmarks, which help forming a mental model of the place (Figure 43). The new concept aligns with the pattern language.

When positioned manually by the firefighter and identified with a consecutive number and a number for the unit, the beacons gain meaning. Beacons become a landmark, a mutual point of reference in the EVER-CHANGING PUZZLE that can support a BACKUP TEAM in finding missing comrades. Presenting this concept to firefighters motivated them to start the second project 'landmarke', 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 to shape the beacons like the wooden wedges that firefighters carry to keep doors from closing in order to allow hoses to move unhindered (Dyrks et al. 2008). The new enhanced wedge, however, not only is to be mounted under doors. It was found necessary to add magnets

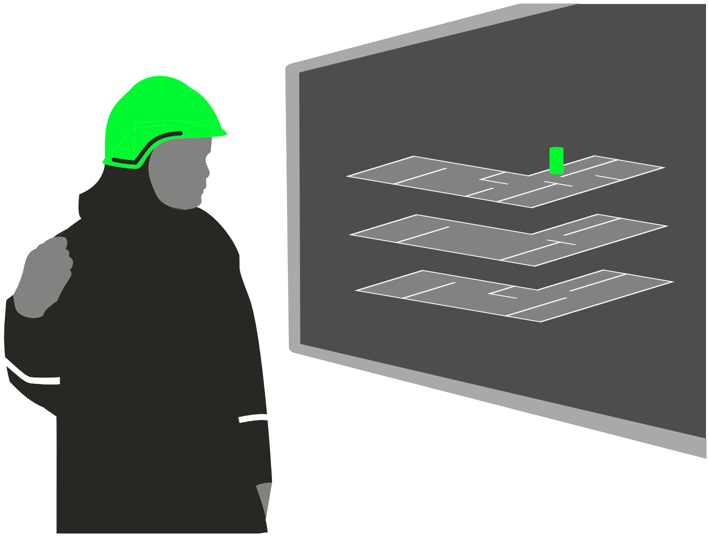

Figure 42: Command post display with real-time position of firefighter

and a hanger to fix the beacon in other places, too, making possible all kinds of MASH-UP mountings with the environment (Figure 43). 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 remote 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, as we translate the signal strength into an LED bar mounted in the breathing mask (Figure 44). In tests with prototypes, firefighters quickly adopted the numeric scales of the LED bar as a SHARED ESTIMATE to exchange information on approximate distances. In combination with the physical graspable shape, the beacons not only become an artifact that is designed for MULTIMODAL ACTS, they also degrade gracefully in case a certain interaction modality fails and thereby follow the pattern TAKE GOOD CARE.

Following the understanding that the novel system also requires new PROCEDURES, firefighters and researchers jointly defined in participatory

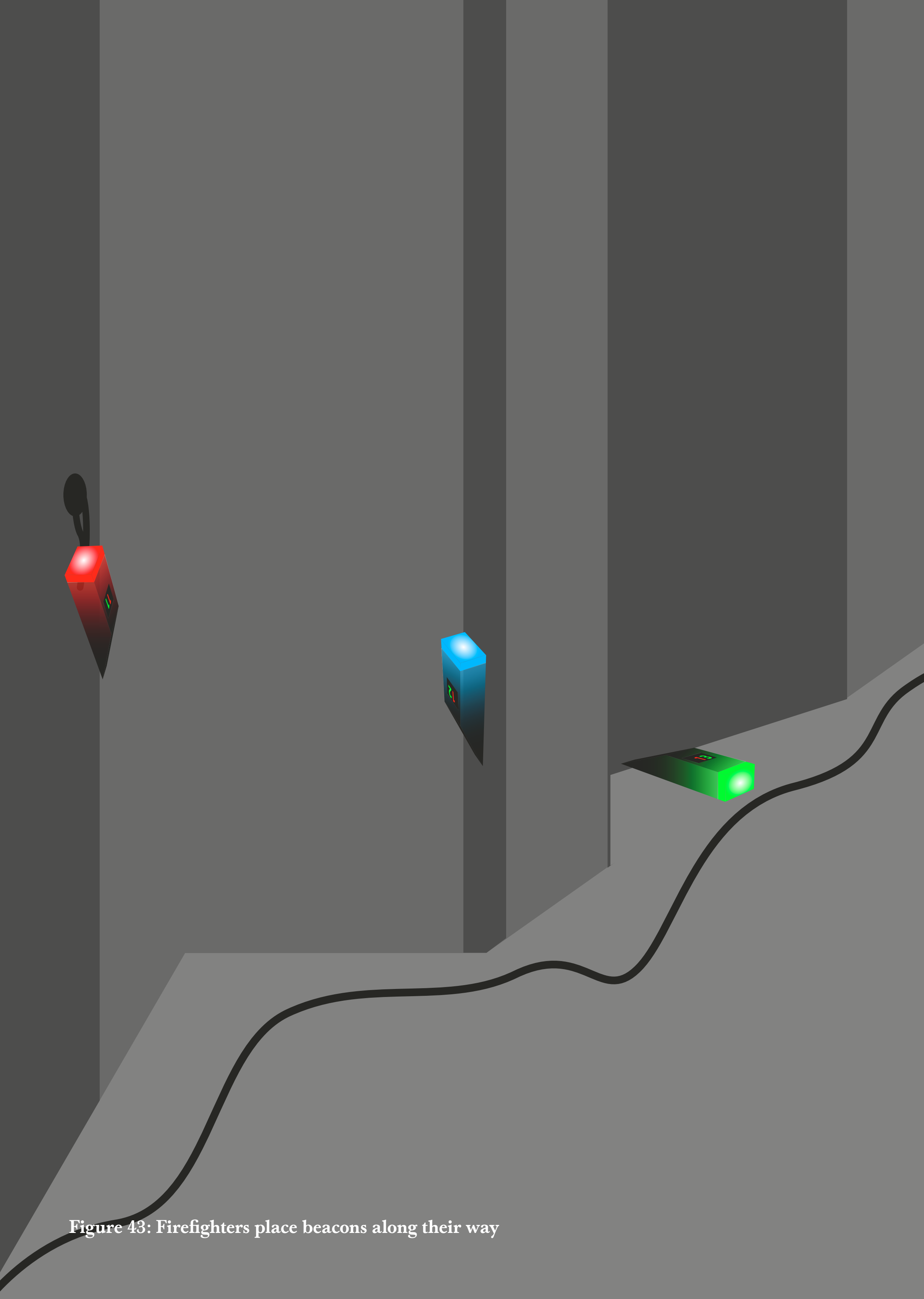

Figure 43: Firefighters place beacons along their way

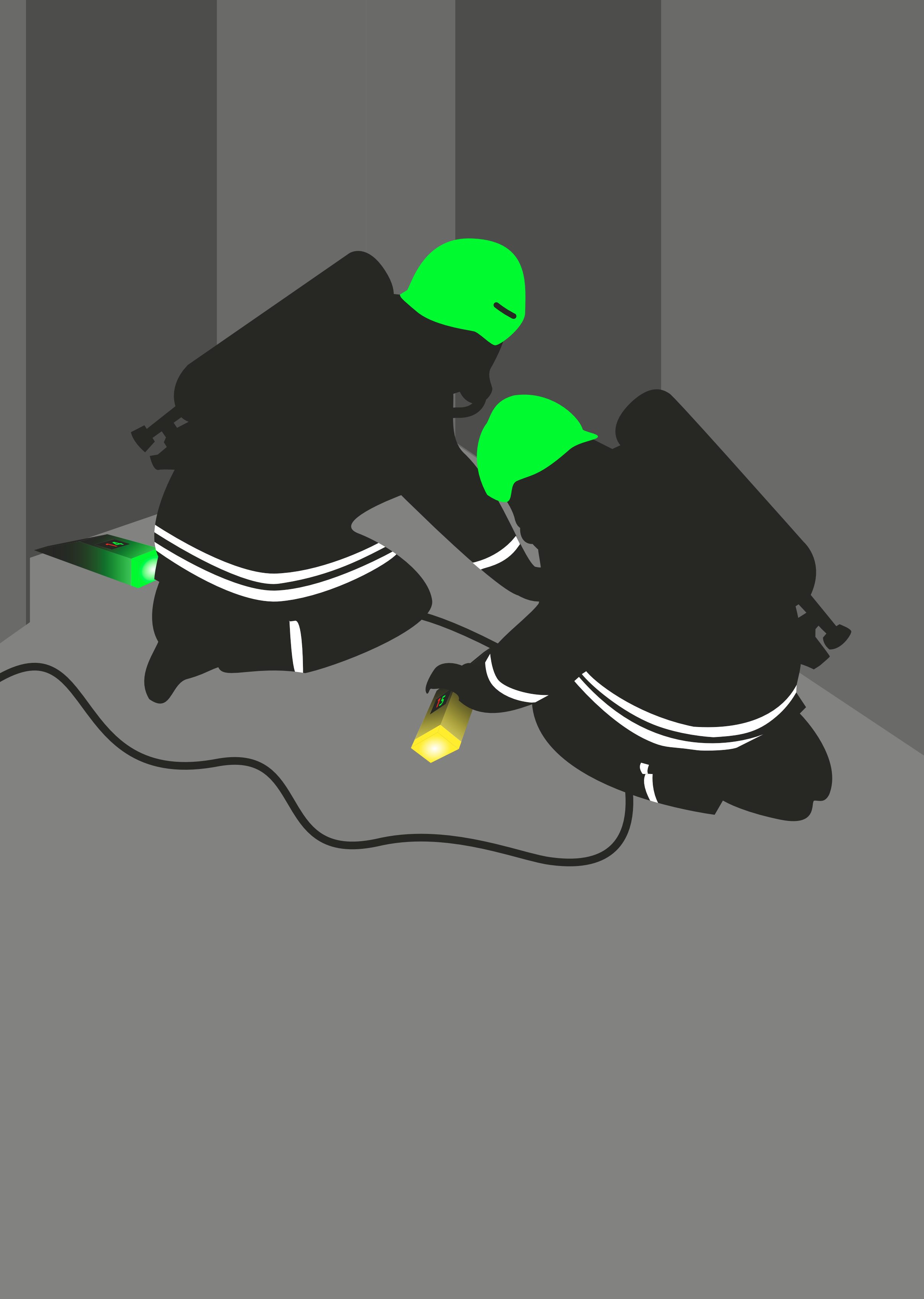

Figure 44: In-mask feedback of signal strength to beacon (left) and prototype of the overall system (right)

design workshops (Figure 22) 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. Firefighters place beacons in the building marking special locations (red), waypoints (blue) fully scanned (green) and partially scanned rooms (yellow) (Figure 43).

Additional discussions also defined that within INDEPENDENT UNITS the last person in the team usually deploys the beacons, as this is the person that has the most free resources as well as the one with the least amount of navigation information. One aspect continuously discussed was the necessity to design the system that might be especially helpful in large building structures, in a way that it is beneficial in all interventions so that firefighter learn how to use in real-world EXERCISES.

While developed with a specific procedure how the beacons should be deployed, firefighters can easily adopt the overall system for other purposes, as suggested by HANDY MULTI TOOLS. The color system for statuses is an open tool that allows the development of new meanings. The different mechanisms to relocate a beacon also open the system for other uses. Beacons could become a means to measure distances, an alternative light

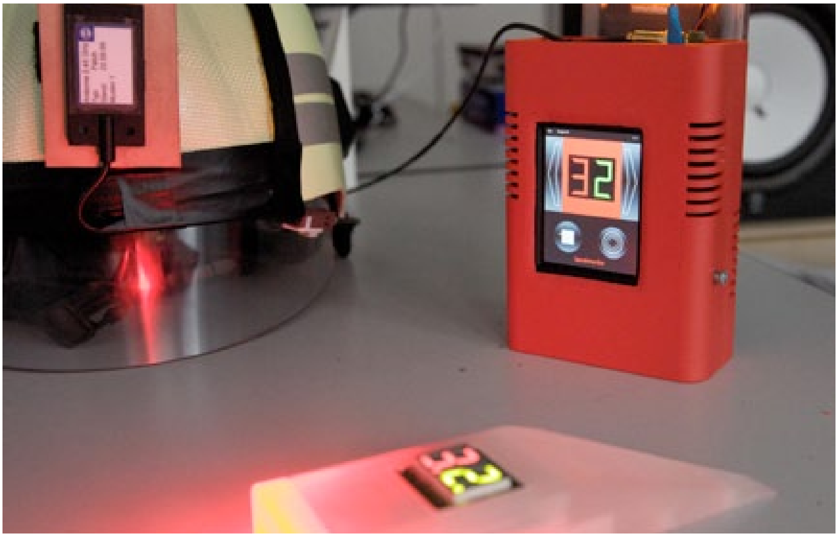

Figure 45: Prototype of landmarke beacon, handheld display
and directional antenna mounted to helmet

source, or a tool for communication when using the remotely triggered audio signals on the handheld prototype (Figure 45) 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 as the firefighters are excited about the system that they enthusiastically describe and promote as a tool with the clear potential to provide valuable support to their work (Figure 46).

6.2 Discussing new Frontline Technology

In a workshop setting, software engineers, who had no previous experience with designing technology for frontline firefighters or other safety-critical environments, learned about the pattern language.

While the landmarke project, described in the previous section, provides an example of a design process that took place while the patterns emerged

Figure 46: Firefighter explaining the system to external stakeholders

and an example for how a pattern language can be used as a reflective tool for rationalizing a system design process in retrospective, the landmarke project could not make use of the overall pattern language as a means of learning and reflecting about the practice.

To understand the pattern language as a means to support technology designers who have no previous background in the firefighting domain, a study comprising a workshop and one-on-one follow-up interviews should build understanding if and how the language allows to form a shared understanding of the practice and how it can be used as a tool for reflective dialogs on novel computing systems for frontline firefighters.

Nine software engineers with backgrounds of computer science, business informatics, media informatics and geo informatics and different levels of experience (ranging from fresh graduates to post doctoral researchers, all male, age 26 to 41) participated in the workshop that introduced the pattern language. All participants had been developing software and were familiar with multiple programming languages. They also were familiar with software development for ubiquitous computing system as they just finished a project developing a middleware for sensor networks.

Figure 47: Workshop room with pattern posters

Of the participants only one had had previous contact with firefighters through his social service with the medical emergency service. Nobody of the participants had previous knowledge about the specifics of the work on the frontline. Also, they were not familiar with the previous work conducted as part of this research. The participants, however, in a current project, were confronted with the task to design computing solutions for frontline emergency response workers and commanders in cross-border, cross-agency operations in large-scale incidents. Therefore, the participants were interested in learning about the work of firefighters on the frontline.

Posters of all patterns on the walls of the workshop room displayed the facing pages that each pattern begins with, showing the photo for the pattern and the summary description (Figure 47). Another poster showed the graphic of the overall pattern language. While participants entered the room and waited for the workshop to start, they could hear an audible representation of the work on the frontline from sounds of firefighters working with breathing apparatus captured at the frontline during the workshops in the training facility in Münster, Germany. These sounds, while to communicating a specific content, should mark the beginning of entering the

Figure 48: Participants reading the patterns

world of frontline firefighting. Each participant received a printed version of the pattern language, almost identical to the one presented in the previous chapter.

After a short introduction and presentation, showing photos from the studies and briefly summarizing the method that led to the patterns, the patterns were distributed among the participants, resulting in an equal amount of text and a variety of not closely linked patterns for everybody. In groups of two or three, participants read and discussed four or five of the patterns for about an hour (Figure 48). In the following, they presented these patterns to the other participants. The pattern posters and the pattern language overview helped to explain and connect the individual concepts. In total, the workshop lasted for three hours.

In interviews, about one week after the workshop, participants explained their understanding of the frontline practice and commented on four technology designs for frontline firefighters that they were presented.

Already with the announcement of the workshop, participants were informed that follow-up interviews would take place in the days after the workshop to collect their individual feedback on the workshop. All workshop participants took part in one-on-one semi-structured interviews, within 7 to 10 days after the workshop.

In the first part of the interview, participants were asked to describe their understanding of the frontline practice. As participants returned printed materials directly after the workshop, they had to freely recall what they remembered from the workshop. Thereby, it was possible to understand their perception of the pattern language and to understand whether the pattern language was easy to understand and to remember and therefore has the potential of being a tool to support a reflective dialog on technology design.

In the second part of the interview, interviewees were presented with an online version of the pattern language that allows the user to jump between the pattern language overview and the detailed description of the patterns. Interviewees were asked to check if they were familiar with all the patterns from their names, and, if not, to check the details for the concepts that they did not remember clearly.

In the third part of the interview, participants were confronted with four technology designs of novel computing solutions for frontline firefighters that varied in scale and nature.

For the first technology concept participants were told about the prototype of an interactive firefighting glove using a photo from the work of Cannon and Rajan (2009). In the concept, each of the two firefighters in a unit wears an interactive glove. By making one of four gestures with their fingers, firefighters can send a message to their colleague. When a message has been received the glove shows a light signal. Additionally, a sensor detects the distance between the gloves and indicates the distance on a four-bar LED display.[2]

[2] This type of interaction differs from the original work by Cannon and Rajan who suggested distance sensors as a means to sense the distance to the closest object.

For the second concept, participants read a quote from a paper by Naghsh and Roast (2008) that describes how a swarm of robots surrounds a firefighting in a building and scans the area for potential dangers. The firefighter receives directional guidance from the swarm of a safe direction displayed using a set of LEDs attached to the visor of the helmet.

The third concept was demonstrated using a video clip from a research project (Discovery Channel and Wired Magazine 2006). In it, researchers present a prototype of a navigation support system that, based on a set of sensors, provides the firefighter a head-mounted display in his mask with a floor plan on which the firefighter can see his current position. When sensors detect a danger in a certain room such as a high temperature, the background color of the room on the map turns red.

The fourth concept was taken from a vision for a future emergency response scenario (RUNES Project 2006). In the video, the authors describe their concept for the future firefighter. According to the vision, the firefighter is equipped with a body area network that combines a number of sensors and new means for communication. All information is displayed in the mask of the firefighter. The firefighter can see outside temperature readings, switch to an infrared display mode, see avatars of the people he is talking to and can get information about victims in his field of view. The outside commander can continuously monitor the location of the firefighters.

After the introduction of the concepts, interviewees were asked to comment on the design by describing, on the one hand, the potential changes that they imagine for frontline practice caused by system and, on the other hand, what technology designer of the system could learn from the practice. Participants were suggested to use the interactive version of the pattern language as a tool to support their arguments.

After the discussion of the four concepts, interviewees were asked for overall comment on how they felt about using the pattern language for discussing the concepts and what they generally thought about the approach of using such pattern language to inform design processes of ubiquitous computing systems.

Each interview lasted about 45 minutes and was captured using an audio recorder. Later, all recordings were analyzed. Sections with relevance for the pattern language were transcribed and translated from German into

English. The data was then analyzed qualitatively, looking for patterns and surprising facts that describe the participants' understanding of the pattern language and how they use it for commenting on the technology concepts.

While sometimes not recalling them by name, participants could explain many of the patterns well. With the pattern overview and the names provided, participants could recall the concepts and therefore use them to discuss the proposed computing systems.

In the beginning of the interview, participants described different patterns. The following participant, for instance, started out with the overarching theme.

> Fluid order, that I remember, of course, this overarching pattern: There is order but it also continuously and spontaneously adapted to the context.

Other participants did not remember all the patterns by name but recalled the concepts.

> The overall pattern that I found very interesting. That is the combination of structure and spontaneity. There was also a pattern that described the hierarchic structure. I don't know how it was called. And the spontaneity was given through the ever-changing puzzle.

For some cases, participants did not recall the English names of the patterns but used words in German that translate to the pattern names in English as in the following example the words "big family."

> I forgot the names, but I know what it's about. First, that they are a big family, I found that clear and important and then this task separation, so everybody knows what he has to do, I still remember, that the chief does not go in but stays with the other people. […] They think about all that can go wrong and are prepared for that.

The following participant, for instance, only used the English words for BACKUP TEAM and EVER-CHANGING PUZZLE, but described INDEPENDENT UNITS, LEARN BY MISTAKE and TAKE GOOD CARE using German words.

> I don't know the name now, that the firefighters form independent groups of two to three people and they then also, once they're inside, have to make independent decisions. That there always has to be a back-up team that is there for any emergencies and is available. That they learn from

> mistakes and they are well documented and they remember the names and that they remember the cases and also that they try to actively live that and how to prevent that. […] There is also the ever-changing puzzle that information is always partly known and that the picture builds up slowly or some parts can change because the situation changes, too. That one has to be careful and to care for ones own safety and the safety of the others, that all is uncertain and one can never know what will happen. […] Also part of the safety is that one has to know the way back.

As the quotes above also show, participants had clear ideas of the patterns and were able to describe them. Only in the discussion later some minor misunderstandings came to the fore, regarding what is part of which pattern, such as this statement on MONITORING that excludes monitoring within INDEPENDENT UNITS from the pattern: "And there was on other thing … no for the monitoring is does not contribute to that … that was for the outside." Such misunderstandings, however, only occurred for patterns that the participants had not read themselves.

With the help of the pattern overview, all participants could recall the great majority of the concepts immediately, as the following example shows, and, after briefly scanning the overviews, could use all patterns as a means to support their comments on the design concepts.

> Independent units, as decision power, decisions are made on-site and nobody can say you are doing this and this and that. Procedures are, they already know what to do, ever-changing puzzle, that they get new information all the time and it therefore can be that what they thought before might be wrong and they always have to update otherwise they can have big problems and life could be lost. Take good care, I am not sure if that means take good care of your friends and team or take good care: watch yourself and where you step. The way back … how they always know how to get back, this lifeline. Multimodal acts that all that they do, because of smoke and all the things, is not only visual but all senses need to be used. Handy multi tools, because they of course do not carry all the things they have fewer tools that serves multiple purposes. Exercise all the time, because the chance for fire is small and that's why we simulate. […] Yes, that was very interesting.

Patterns help to identify mismatches between practice and certain aspects of the design proposals and help to identify missing features in the systems.

When comparing the proposed designs and the practice described in the patterns, participants identified mismatches.

Both the proposed systems with the robot swarm and the head-mounted display, for example, pictured the firefighter as a person working alone and did not include information about the interaction with other firefighters such as mentioned in INDEPENDENT UNITS or RIGID STRUCTURE. For the system with the robots an interviewee commented:

> First I ask, why is it all about one firefighter because usually they are together with others and this sounds almost like as if one would like to replace the teams with robots and one says that when the robots are there it is enough if one is alone and this I doubt a lot.

In a similar manner, another interviewee commented the system with the head mounted display displaying the position of the firefighter:

> Actually there was nothing … that is all about the individual firefighters … there was nothing about a whole unit that works together or a command post that can intervene but it was an individual means of support. I am not altogether congenial with that. At least you should also directly display the team members.

For the same system, interviewees also saw the need to integrate updated, dynamic information in the system to support the EVER-CHANGING PUZZLE. While the video did not explicitly talk about whether or not the displayed map can change, participants identified this as an important aspect. One interviewee referred more generally to the problem, he said: "The problem is how current is this information, how static? […] If the building burns the structure can change." Others specifically mentioned the pattern:

> An interesting question is, when for instance information is changing with the ever-changing puzzle, how they can adapt that. When they for instance notice that here is a door impassable or we notice that this was reconstructed.

> I see a problem with the ever-changing puzzle, how recent is my information? There [on the map] it still says 'the room is safe' and I go in and there is a big conflagration and the backdraft. How well can I rely on that

> information or how do I add new information? I cannot imagine that someone really relies on that information and says 'great, I can go in.' He will still feel with the hand […] and feel step-by-step with his foot. […] What's about the ever-changing puzzle? That would be my exclamation mark. Here's danger lurking for an IT system.

Beyond the focus of particular features, patterns support the discussion of overall design concepts checking how systems can be used as part of the existing practice.

Apart from adding features from the patterns to the proposed systems, participants discussed how the systems match the frontline practice overall, by asking how they can be used by firefighters.

For the interactive glove, for example, some participants questioned the core concept of distance sensing in relation to MULTIMODAL ACTS and thought about the value of touch that firefighters currently use to stay aware of each other. One interviewee commented: "Why should I have a message system, if I can touch the other [comrade]? […] I find a touch much richer than such a signal." Another described it this way:

> I ask myself: It is always the case that two stay together, that's how I understood it. If that would change that … if one, without having visual contact, always knows how far the other person is away. […] Actually, this converts the distance felt by touch with a visual input. But if you touch your partner you can not only know the distance but also learn for instance that there is a step because your partner might be lower than you.

Another participant questioned the glove concept in relation to MULTIMODAL ACTS by pointing to the value of spoken communication:

> That here is multimodal acts: That one uses the different senses to grasp the situation and to … and this is additional information. But if one communicates, I think that one in most cases also with the voice, can talk to each other, because you're not that far apart within a team.

For the system with the swarm of robots, interviewees used a number of different patterns to check the concept. They discussed, for instance, the pattern INDEPENDENT UNITS:

> I don't like "the swarm of robots determine a direction that the firefighter has to follow." [Quote from the description of the concept] If that means

that the robots decide and you just have to follow that would not work. That is a sign of independence. […] I am not sure if the independent units would be so independent if the robots say everything.

The only point that bugs me a bit and that even, when coming back to the patterns, to these independent units. People are distributed and they have their own responsibility and they say we go this way they briefly exchange information and look for their route. I can imagine that a firefighter also is somehow a warhorse that means he wants to struggle through, of course in safe way but he make his decision using his experience. If he is told by a control unit 'No, not this door but the next door right' and without reason, he would say 'I am not listening to that technology.' If, of course, the robot swarm who has walked ahead, says 'the temperature is too high here' or 'it is toxic' or because of this and that reason, then it would be a support. I can imagine […] that they would prefer had a mini group of swarms that they can send somewhere. […] They [the robots] go inside then I do not have to stretch my leg anymore.

Mentioning the pattern EVER-CHANGING PUZZLE and aspects of the patterns SHARED ESTIMATES and TAKE GOOD CARE, another interviewee asked, in a similar manner, for more transparency in the data communication:

I think that the information has to be precise, or, how should I say that, it should not be like that, it is, I believe, difficult if these robots somehow capture a lot and then conclude something and then they say 'attention here is a dangerous obstacle'. Because you are somehow skeptical. How does the robot know that? So in principle from this puzzle and from this information that I have, I want to make my own guess how the situation is, I believe, because I have the experience and not the robots. It has to be like that that the robots if they measure, feel, somehow, that this one-to-one goes into this puzzle.

In another comment on the system, an interviewee pointed to the importance of the role and use of the information provided by the robots. The operation is described safe when the patterns TAKE GOOD CARE and MULTIMODAL ACTS are fulfilled at the same time.

It really depends how one uses it. It is an important question if the robot tells the direction or if not. If I see it as another sense, multimodal acts, or if let myself be guided by the robot. That means, I take care anyways where the danger is and I take this as an additional input channel but do not rely my decision on it too much and rely actually still on that what I had before and if it says 'right' and I know from experience that straight would be better, I nevertheless go straight. I think it would be better if it would be used in such a way that the robot is not fundamental in the decision process.

The future firefighting scenario, presenting an overall, seemingly perfectly integrated system, made participants use different strategies for applying the pattern language as a means to talk about overall system concepts.

Immediately after the video finished, an interviewee commented: "This is a lot of information, this is like a computer game." When asked to inspect the system more closely, he used the patterns as a checklist to evaluate the system and could solidify his critique.

> OK, the ever-changing puzzle is OK, monitoring is OK, but all those multimodal acts, here there is so much information in the visual channel. That's overwhelming. OK, the way back if they have a pretty big display, OK, that will be better and infrared cameras in smoke situations … ever-changing puzzle OK, everybody can have all the information. But, I don't know which pattern this was that the people feel in control, I don't think that was a pattern, maybe these independent units? Exactly.

Another participant described that the system will endangers existing patterns. He also envisions a new pattern that will be required to handle the new system.

> As I see it, based on all this data they give instructions. […] That is maybe a new pattern 'remote instruction' or so but things like skills such as mash-up or handy multi tools are lost.

While discussing the concept of HANDY MULTI TOOLS an interviewee discussed the nature of the system design and how it compares to existing tools for firefighters. In his remarks, he described the relation between tools and tasks in the same way that databases are designed. From this perspective, he can identify that the proposed system has a very different relation between tasks and tools.

> I think they [the firefighters] do not want to rely on technology but better use it as tools, for specific tasks, there are also multi-tools that support many tasks. There is not a one-to-one relationship, this tool for that task, but one tool supports many tasks. And here it is even so, […] it should cover everything and the suit should cover everything. So this is a one-to-many relation reversed from what is currently being done, namely that I

> have a small tool and that is for multiple tasks, here I have a tool, namely the suit and it is responsible for everything. I think this is not good.

Whether or not one might agree to the statements made, the above quotes on the systems by the participants are broad, as they touch many aspects of the systems, and rich, as they are very specific on certain aspects. Thereby, the quotes above are examples on how to start a reflective discussion on the overall concepts of the proposed systems in relation to frontline practice.

In a number of examples, the pattern language served participants as a means to contribute new features to the design proposals and redirect overall concepts.

In different cases, participants called for improvements or changes to the proposed designs that they derived from the patterns. Such changes can include the features of the system.

For the interactive glove, a participant suggested an alarm to be triggered if the sensed distance between members of the INDEPENDENT UNIT becomes too large.

> One idea, for example, if the glove recognizes if the other person is too far away that it signals that […] What I spoke about was that with independent units that they should take care for each other, that it [the systems] tells them 'you have forgotten your partner somewhere.'

In a similar manner, a participant suggested the inclusion of MULTIMODAL ACTS for the future firefighter scenario.

> I think that [multimodal acts] was not taken into account but it would be good to do so […] The system realizes if somebody cries but it gets overlaid by the fire. It can tell the firefighter, 'you, listen to the right there's something important.'

For the head-mounted display, the pattern THE WAY BACK made interviewees suggest a feature that would include that return path on the map. An interviewee described this aspect by making a case in which he actively tried to use a pattern as a means to search for a missing feature and also as a direct means to provide the design solution.

> It would be good, if one could say, from this pattern, this and that has not been included and one could include it in this and that way. I try if I can find something. What was again "the way back" [reads the pattern

> for 15 sec]. Yes, this has not yet been included … at least I have not seen it in the video. So if this really has not been included, one could say that it is important that the way back is always clear and this could be either integrated through visual clues, you could integrated that into the heads-up display, or using the rope. But I think the rope already exists, I would assume now that it did not get replaced by the system.

The approach in this case is to retain the existing practice and ensure that the patterns become reflected in the design. The proposed solution represents a linear transfer of an aspect from the pattern to the design of the computing system.

Different from adding new features inspired by patterns, an interviewee, for the systems with the swarm robot, invented a new way of using the system and suggested a new **PROCEDURE** for firefighters using the system. In the proposal, instead of receiving directions from the robots, the firefighter can control and send the robots as a new means for **TAKE GOOD CARE**.

> My procedure would be: I do know the place and if I do not know something I send my scouts. By that way I fulfill 'take good care' […] I do not need to feel with my leg [the surrounding, as described in the pattern,] but I know [from the robots] that the floor is strong enough.

For the future firefighter scenario, another interviewee, while not directly making a change proposal for the design, used **SHARED ESTIMATES** to point to an aspect that is missing in the overall system and, when considered in the future, could again empower the on-site firefighters.

> For example those shared estimates […]–I actually like these shared estimates–they are maybe missed out, they are neglected. You do not ask the firefighter on-site 'how do you assess the situation?' but instead you rely on this collected data and fuse the data […] and make decisions.

The above examples of a glove system that does not replace the touch but becomes active in emergency cases, ahead-mounted display that displays the firefighter's path, a robot swarm that is controlled by a firefighter and a smart system that also allows for input from the person on-site, show how the pattern language can be used in order to change system designs so that they are more compatible with the existing practice.

Using the patterns requires envisioning transformations and their potential impact. Views and perspectives can be highly subjective sometimes.

While the quotes above might give the impression that participants shared similar views on the systems, this was indeed not always the case. As reflected in the different comments, individual participants held contrary positions concerning if and how the proposed system influence firefighting practice. Putting these statements next to each other shows the contrast.

For the robots, one participant argued:

> They [the robots] […] give a bit of additional information. That is all that they do. About rigid structure, they are at the end of the food chain. Of course they do not belong to the family. Independent units … Well, they have a guy that they belong to. […] If the robots do not stand in the way, I have no idea what kind of influence they should have.

For the same system, other participants had different views on potential changes. "I am not sure if the independent units would be so independent if the robots say everything," was one statement. Others noted: "[The system] maybe contradicts this take good care because I go without thinking because the robots say everything is safe," and questioned the information provided by the robots "Can a robot capture the same multimodal acts as a human? I would doubt that." They also commented on the impact and role of the robots that, in the original comment mentioned above, was neglected.

> Well this big family is based on experiences, incidents that you have experienced together. So maybe he had saved my life and then you saved my life and with a robot and big family … this, I imaging to be difficult.

Another interviewee added to the point:

> I am not sure, if you can build trust to such device as a human or firefighters. If he really trusts them the way he trusts a colleague who takes off the glove and checks the temperature.

In another case, a participant talked a about the future firefighter scenario that provides a firefighters the visor display with all information. He said:

> I think there are of course things that do not change. Rigid structure, big family, it [the system] has no influence on that. It only provides him information. It does not give instructions. […] We still have rigid structures I have the command post that is in control and I have the people in the field

> who have their tasks, they just do them. Then I have procedures, they do what they always do and get additional information or send information without the need to take about that. Fulfilled as well. Monitoring very clearly fulfilled. Ever-changing-puzzle even, too. That is the thing that gets covered that means we collect information hand it over and get input back. […] This take good care, technology has nothing to do with that, he acts, the firefighter of the future, he would need to do the same, what he always does. Feeling, sensors and feeling and being careful, he always does that. […] If this visor helmet stops working, they can work as before.

The other interviewees had a different view on the system. The following example is from a participant who had an overall very different perception of the system, for him the system would entirely change firefighting practice.

> What would be changed a lot would be those multimodal acts if I only take a look and get all kinds of information, temperature, there's a living person […] in the end it's only about moving yourself to the place, to do something and going back out. Everything else is handled by technology. […] Finally, everything would change absolutely everything or almost everything with monitoring, the way back and take good care and everything that deals with technology and not with emotions like big family. One can send and idiot inside. Maybe one also does need the big family anymore as all critical situations are prevented.

Interestingly, the positions of individual participants varied. An interviewee, for instance, did not envision the robots to influence the frontline practice at all but foresaw a number of practice changes for the future firefighting scenario.

The pattern EXERCISE plays a special role in the discussions. It is an open question what this concept means for technology designs as large changes could be simply transposed into a need for more training.

In different cases, participants referred to the patter EXERCISE when they foresaw that a system poses a large change for the existing practice. For the head-mounted display, for example, an interviewee stated:

> Well I would fear that this would require a lot of exercise […] that they do not concentrate on the display, 'third door right', and I see 'cool I see where I go' but that they really only look into the display, because otherwise they loose […] the sight of the terrain.

Another interviewee commented on the same system:

> Well that is not a new modality but a new perception for sure that one maybe through a lot of practice and training can be internalized that one does not realize it anymore.

While the previous example only discussed relatively small changes, the firefighting future scenario may require a more dramatic shift.

> That would completely change the way of working as a firefighter. If one really has all the information, sensors everywhere … this would be in the end … This firefighting practice is a thing that has been established over a long time and in which there is a lot of experience and routine. And if one introduces something this extremely novel, that would have to be trained for a long, long time so that one gets routine with this new technology.

It remains, however, an open question whether or not training could solve the problem of using the display. Arguing with EXERCISE one could easily get the impression that any system can be introduced as its issues can be solved with EXERCISE. These statements do not the amount of training that would be adequate for the introduction of the system. At least in its current state, the pattern EXERCISE in firefighting frontline practice does not provide a means to support radical change. While the contribution of the pattern language is to identify the potential size and nature of the changes posed by new technology, adaptation problems will certainly not be entirely solved by EXERCISE.

Rather than providing distinctive answers, the pattern language serves as a means to formulate more specific questions about the consequences posed by novel technologies.

Participants discussed the proposed systems and the changes that they may cause for the patterns. More than speculating about the changes, participants sometimes expressed that they are unsure about the impact. In the first example, an interviewee commented on the map displayed on a head-mounted display as a potential change for the relation between commanders and subordinates.

> There is a lot of additional information. I am not sure if that would make the commander redundant. As he usually is the one who has the over-

> view of the situation and in this case the firefighter has the overview himself. It could be that the commander is redundant. About hierarchy, that there is one who says what to do. I am not sure. I guess that would change the relation between firefighters and commander.

In another example, another interviewee commented the same system and its impact for the pattern TAKE GOOD CARE. He left open the potential impact and called for a study to investigate the influence.

> Take good care–could be positively and negatively affected. As far as I remember that was that anything can happen and that one has to be ready that something unforeseen happens. […] But I could imagine that when one relies on it too much, one gets less attentive, could be negative, one would have to study that.

In this way, the pattern language serves as a tool for developing questions to be answered by further research.

In retrospective, participants ask for a more detailed description of the links between the patterns. They welcome the patterns as a relevant tool for discussing the design proposals.

Following the discussion on the proposed concepts, participants were asked to summarize their experience with the pattern language for discussing the proposals.

After the workshops and interviews, participants asked for a more detailed description of the links that connect the patterns. While reading their focus was on an individual pattern and they wanted to learn about all the connections from this pattern to the other patterns. Therefore, in the version of the pattern language presented in this thesis, the linking of the patterns has been improved throughout the pattern descriptions and is summarized in a closing paragraph for each pattern.

Beyond this issue of the links between patterns, in the participants' feedback, the value of the language as a means to talk about the novel systems became apparent: "This is a manageable number of patterns that give this frame to talk about it," a participant stated and continued "For me this is now, so to speak, the basis and my picture of the firefighting domain." When asked for the understanding of the individual patterns, another interviewee added: "I find them to be well-defined, I would not say for anything that it is no individual pattern for me."

Another participant focused on the patterns as reminders for aspect that might otherwise get forgotten. He said:

> 'Multimodal acts', I would for instance not have thought about that. This idea I would not have had […] This really helped to think it through. Also the 'exercise' would not have come to my mind.

Taking the pattern language beyond the workshop, another participant envisioned the language used as a shared glossary in his project context with partner from different organizations.

> Everybody has a certain idea and they talk about it but they cannot hurl a word at each other: 'ah that is what he means' and that works this way. If I now ask somebody: 'Did you ever think how your technology supports those multimodal acts?' Then he knows exactly, OK, it's about this more sensible perception of information with the senses and thinks about how that fits into his technology.

As these quotes and the previous examples show, during the discussion the pattern language becomes an important means of communication for commenting on technological proposals for frontline firefighters.

7 Discussion

Similar individual and interacting patterns have been described for firefighting and other high reliability professions. The presented pattern language, beyond these aspects, reveals the importance of INDEPENDENT UNITS *and provides an integrated perspective on frontline work. The pattern language can feed into participatory design processes of ubiquitous computing, it can evolve with the changes posed by technology.*

7.1 Firefighting and other High Reliability Professions

A comparison of existing research and the proposed patterns helps to reflect on their contribution. Selected patterns and aspects of patterns have been discussed in previous research or documents on frontline firefighting.

Following the tradition of grounded theory, I shall now review the understanding of firefighting frontline practice that I have presented as a pattern language using previous research on firefighting literature and literature from other high reliability professions.

As the review shows, individual patterns or aspects of patterns have been discussed in other research.

The need for a static hierarchy and strictness, as presented in RIGID STRUCTURE, are part of published work. For the case of the Mann Gulch disaster Weick states that "what people needed was a structure in which there was both an inverse and a direct relationship between role systems and meaning" (1993: 646) and that a "major contributor to this disaster was the loss of the only structure that kept these people organized, their role system" (1993: 636). Researchers, more recently, also study the incident command system–a management structure for firefighting and other emergency response organizations. The incident command system has been widely introduced and has become a standard at U.S. firefighting academies. It suggests a RIGID STRUCTURE and PROCEDURES to perform the incident command for operations, planning, logistics, finance and administration. The system is "highly formalized, characterized by extensive rules, procedures, policies, and instructions" (Bigley and Roberts 2001); yet it is designed to be scalable. Multiple functions can be hold by a single individual. Thereby, the system can be applied from firefighting operations performed by a single engine to large scale incidents that comprise several hundred first responders. Bigly and Roberts show that the incident command system works as a mechanism that helps to develop a structure while the incident develops after the initial alarm. Firefighters, however, also report that commanders may set-up structures too extensively and then lack personnel that work on the ground and actually extinguish fire. Compared to the RIGID STRUCTURE pattern, their research does not include the notion that RIGID STRUCTURE is also an expression of mutual responsibility and trust that extends beyond the firefighting incident operation.

Other patterns are described in literature stemming from the firefighting community. PROCEDURES, EVER-CHANGING PUZZLE, MONITORING, THE WAY BACK and BACKUP TEAM are aspects that are, at least to a large extend, well-defined in firefighting training books and regulations (e.g. (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe 2005, Günter et al. 2009, Klingsohr 2007)). Official reports also show the practice described in LEARN BY MISTAKE. PROCEDURES and EXERCISE are changed according to accidents (Thiel and Stambough 1999). The patterns presented in this thesis underline these aspects.

The importance of EXERCISE is also described by Weick who refers to the psychologists' finding that people rely on trained behavior in stressful situations (e.g. (Barthol and Ku 1959)). Weick argues:

> When people are put under pressure they regress to their most habituated ways of responding […] What we do not expect under life-threatening pressure is creativity. (Weick 1993: 639)

In this work, beyond Weick's understanding, the pattern shows that EXERCISE is not only for learning how to follow fixed PROCEDURES but also a means to train their divers applications, to create physical experience and to learn how to MASH-UP. EXERCISE becomes also a training of creative acts.

Research on high reliability organizations provides an integrated perspective on a number of patterns and describes the interaction and interdependency of patterns.

Besides the work that highlights certain patterns as important for firefighting practice on the frontline, other research on organizations faced with safety critical tasks shows how practice patterns interact.

In his book entitled 'normal accidents', Perrow (1984) argues that failures of systems–especially those that are highly complex and interdependent–are inevitable since small incidents can have major, unforeseen consequences. Catastrophes are caused by unforeseen combinations and interactions of system components. It is therefore only a matter of time that partial failures in complex system assemblies occur and lead to tragic results (Perrow

1984: 32). Fighting the inevitable, Roberts et al. (2001) show that complex organizations for whom high reliability is crucial, so-called 'high reliability organizations', have developed effective strategies to prevent or minimize the effects of accidents. Across disciplines and in all kinds of contexts high reliability organizations–from medical staff in hospitals, to labor in large production facilities, sailing ship crews and navy military on aircraft carriers–apply certain patterns that help to act in arising crisis situations effectively.

Roberts et al. (2001) list three major themes in which these patterns can be categorized. First, as described in TAKE GOOD CARE, PROCEDURES and LEARN BY MISTAKE, these organizations seek to understand the unknown that might be causal to crisis situations. Second, these organizations install reward systems that honor prevention and detection of possible threats. While there is no explicit reward system in firefighting practice, the strong social bonds described in BIG FAMILY and the direct negative impact of mistakes on the firefighters cover this mechanism. And third, enhanced communication, as described in EVER-CHANGING PUZZLE or SHARED ESTIMATES, allows the members of these organizations to understand their individual action as a part of a larger context. As a result, individual actors are empowered to act in critical situations based on experience gained in EXERCISE, running organizational system and effective communication.

Adding details to the concept of effective communication, social psychologists studies the effective communication between different actors (Campbell 1990). The study shows the need for mutual trust and the need making the best use of each other's reports, as described in EVER-CHANGING PUZZLE and SHARED ESTIMATES. Successful information sharing requires mutual trust (BIG FAMILY) by respecting the reports of others and be willing to base beliefs and actions on them. From the perspective of the person reporting, records need to be made honestly so that others may use the observations in coming to valid beliefs. The communicating individual needs to respect her own perceptions and beliefs and should seek to integrate their reports with the reports of others without deprecating their own or other's information. (Campbell 1990: 45-46)

As an especially challenging example for a high reliability organization, research from the work on naval carriers shows that EVER-CHANGING PUZZLE, TAKE GOOD CARE and LEARN BY MISTAKE are essential aspects of successful practice. The crews of naval aircraft carriers face a unique work environment that comprises different of high-risk technologies. A large number of airplanes operating on an extremely small space, ammunition and other military technology, all on a nuclear-powered ship, bear high risks for the crew and equipment. Yet, despite the high-risk environment, the carriers operate safely most of the time. Weick and Roberts (1993) studied the operations to analyze what makes the system succeed. In particular, they focus on the interactions among the different actors on the carrier and in the planes to understand the success. Weick and Roberts use the concept of 'collective mind' and of 'heedful interrelation' to describe the organization. Optimizing the reliability of the entire organization is accomplished through 'heedful interrelations'. Here, the individual acts attentively, alerted and careful, when interacting with his colleagues similar to the concept of TAKE GOOD CARE. Thereby the organization jointly forms a 'collective mind' to which the individual actors contribute and that creates a level of safety to avoid crisis situation (as described in BIG FAMILY, EVER-CHANGING PUZZLE and SHARED ESTIMATES). As Weick and Roberts (1993) show, a lack of communication and a lack of heedful interrelation is causal in cases when things go wrong on a carrier. Remaining heedful in the way newcomers do, appears to be a key principle. Aging teams therefore face the challenge to prevent routines taking over the heedful attitude.

INDEPENDENT UNITS and in consequence MASH-UP, MULTIMODAL ACTS and HANDY MULTI TOOLS are special concepts in frontline firefighting; other high-reliability organizations have other means to gain flexibility.

While other patterns are clearly visible and frequently mentioned in firefighting literature and research of other high-reliability organizations, foremost INDEPENDENT UNITS, but also MASH-UP, MULTIMODAL ACTS and HANDY MULTI TOOLS are not as present. Nulden (2003), for example, studies the practice of police officers on patrol, and while he shows that police officers sometimes act in local autonomy when responding to local needs, they, at the same time, remain more closely integrated in the overall organization, as they feed their actions on-site back to the command center.

The independence of firefighters inside a burning building is not something initiated by human thought, by preparation or training. Instead, the isolation is enforced upon the firefighting organization by the hazardous work environment, the need to respond quickly and limited human resources. It is this isolation that requires firefighters to MASH-UP, to perform MULTIMODAL ACTS and to make use of HANDY MULTI TOOLS.

INDEPENDENT UNITS represent the social nucleus of a firefighting operation, the smallest possible unit. Weick already showed that having at least one partner is crucial.

> A partner is a second source of ideas. A partner strengthens independent judgment in the face of a majority. And a partner enlarges the pool of data that are considered. (Weick 1993: 642)

For frontline firefighters, INDEPENDENT UNITS, certainly, come with great risks. Getting lost, experiencing a threatening situation is a risk of life for a firefighter. Yet, the isolation also provides the units an open space to work in. Clearly, using technology to bridge the gap to the frontline has the potential to bring about more safety to a hazardous environment. Yet, the current system also needs to be respected as a working one, where balance has been established. Indeed, such independent teams can be understood as a highly decentralized structure that is suggested as a success criterion in combination with a strong culture and supportive leaders by studies on innovation management. (Tushman and O'Reilly 2002)

Research shows that other high reliability organizations have developed individual strategies different from INDEPENDENT UNITS to gain flexibility. At nuclear power plants it is 'conceptual slack', as Schulman (1993) named it, that helps to ensure safe operations. Schulman defined 'conceptual slack' as the "divergence in analytical perspectives among members of an operation" (Schulman 1993: 364). This slack in an organization combined with shared, and sometimes even ambiguous lines of responsibility builds a climate in which every problem gets reviewed from different perspectives. Basically, the organization implements a less stiff RIGID STRUCTURE. Schulman also shows the importance of mutual respect and trust (**BIG FAMILY**). Frequent conversations among members of the different teams, who get selected also for their social skills, ensure that each other's credibility is sustained. Such structures can easily be dismissed. At the plant an inspector analyzed the organizational system and complained "It's hard to get anyone here to own up something" (Schulman 1993: 370). A nuclear power plant is operated under thousands of procedures and is strictly regulated from various outside agencies. Every operation has to be documented; numerous protocols are in place. Schulman describes in detail how, for instance, maintenance worker have to sign a sheet of paper stating on which of the two units they are working on to avoid mix-ups of the two identical units of the plant (Schulman 1993: 367).

Interestingly, in a similar understanding as identified in firefighting frontline work, the organizational design of the nuclear plant is rooted in the understanding that even with all the rules and procedures in place this system is not immune. The running system is more complex than what is captured in defined procedures; there are problems and issues that simply have not been detected yet. Therefore, the organization has to remain partly open. The falsely dismissed slack provides the nuclear plant the flexibility required to answer unforeseen situations. Even though the concept of 'conceptual slack' is quite different from the strategy to gain flexibility through **INDEPENDENT UNITS** in firefighting, the general understanding that safety cannot be guaranteed by **PROCEDURES** alone is the same.

The tension between the needs for structure and flexibility has been discussed in management science for other types of organizations.

The contrast that surfaces when studying the inner workings of firefighting organization between efficiency on one side–as a result of **RIGID STRUCTURE** or mutually agreed **PROCEDURES**–and flexibility on the other side–as a result of **INDEPENDENT UNITS**, **MASH-UP** or **HANDY MULTI TOOLS**–has also been discussed as the trade-off that constitutes the "paradox of administration" (Thompson 1967: 147). More recently, Adler et al. (1999) have challenged this view and showed that different mechanisms allow organizations to achieve efficiency and flexibility at the same time. Such mechanisms include meta-routines that allow workers to build new routines as a result of an innovative process, enrichment of the work through new activities and the division between non-routine and routine tasks and their assignment to different groups. This is what firefighters do in MASH-UP or in HANDY MULTI TOOLS. While other researchers have challenged the effectiveness of such methods due to various impediments, Adler et al. (1999) show that those obstacles can be overcome through a cultural setting and a trusted management (as described in BIG FAMILY) and that thereby an organizational environment can be established that allows for high efficiency and flexibility at the same time. Training (EXERCISE) and mutual trust (BIG FAMILY) are critical to organizations that need to be efficient and flexible at the same time. (Adler et al. 1999: 63)

The patterns provide an integrated perspective on different aspects in frontline practice. The pattern language links together various aspects of frontline practice and reveals their interaction and interdependence.

As this look on the previous research has shown, individual patterns and combinations of patterns can be linked to the results of existing research. Beyond firefighting, similar concepts are part of work practices in the work context of other high reliability organizations.

For frontline firefighting, the identification of the patterns INDEPENDENT UNITS, MASH-UP, MULTIMODAL ACTS and HANDY MULTI TOOLS, helps to understand how firefighters respond to the isolation that they are confronted with.

More important for the design of ubiquitous computing tools than the application of individual patterns, however, is the perspective that the patterns in their interaction, linked as an overall pattern language, help to understand the configuration of firefighting frontline practice.

7.2 Designing Configurations

The pattern language is not to be confused with a set of constraints for the design. It instead prepares the technology designer in different ways for making the jump from an understanding of the practice to the design.

This thesis has started out by arguing that the design of ubiquitous computing artifacts is also a social endeavor and that technology designer need to understand the interaction between these artifacts and existing practice. So how does the pattern language become integrated in that process?

As the study presented in the previous chapter shows, there is not necessarily a direct or unique link between this description of the practice and the design. While there are cases in which a clear mismatch between practice and technology concepts can be identified or missing features could be added, in most cases the problem does not only have a single answer and requires an open debate.

Consequently, a pattern language does not provide a path from ethnography to design that can be easily passed, where the next step is defined by the previous, following a logic set of rules. The patterns, especially when decontextualized from the overall pattern language, are not to be confused as a constraint, a 'Sachzwang', as Rittel (1976) discussed it, that "owes its eerie existence to the need of decision makers to secure themselves." He adds:

> The decision maker has to try to fathom the system of constrains as completely and realistically as possible. He will only notice how thoroughly he was post festum, by the consequences of his decision. Taking a precise look, however, reveals that the constraints, not at all, are as hard or objective, as this argument may suggest. (Rittel 1976)

Even with a pattern language in place, it is not decided that the patterns could not change or that one pattern might not be emphasized over another. The pattern language does not provide an easy answer to the question if or to what extend a certain pattern or the overall language could or should be changed in a design process. This question is not to be answered universally. Defining and reflecting the potential or actual changes, remains the goal of a careful interaction between users and designers. For each design, the balance between and interpretation of the individual patterns needs to be reconsidered. Design remains a value sensitive endeavor as the pattern language does not suggest the design nor can the design be derived from the pattern language. There is no single or easy bridge between ethnography and design. Instead, the pattern language, in a number of ways, prepares the designer in making the jump.

First, a pattern language serves as a rationale in design processes to reflect on practice change.

The idea of using pattern languages as a rationale for design processes was already foreseen and proposed by Erickson (2000a: 366).

In the design projects, the pattern language became a means to reflect the design process and the two alternative systems 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. Here, the beacon-based systems provides an alternative and directly supports INDEPENDENT UNITS. While neither option is per se good or bad, the pattern language allows discussing the impact of these systems on the existing practice. The patterns provide words to talk about the relation of artifacts and practice. Breakdown situations that occurred in the workshops, for instance when using the initial prototype, can be analyzed in the framework of the pattern language. While the context, 'frontline firefighting', is relatively rigid and manifested in EXERCISE and PROCEDURES, other contexts might allow for more radical changes that a pattern language can help to make visible and thus discussable.

As a rationale, the pattern language also helps to understand existing systems in frontline firefighting. Analyzing, for example, the two computing devices found on today's firefighting frontlines, namely the PASS devices and thermal cameras, allows to explain how the devices are well integrated into the existing system.

The thermal camera is a rather bulky device and weighs an extra three pounds, nevertheless, it provides meaningful for firefighters on the front line. It is a tool that provides firefighters a new sense to perform MULTIMODAL ACTS that directly increases their capabilities for navigation and supports the search for missing people, a tool that supports INDEPENDENT UNITS on the frontline.

The movement sensor devices of the PASS (The Personal Alert Safety System) embedded in the breathing apparatus also provide a concept that for the largest part preserves the INDEPENDENT UNITS. The sensors allow the firefighters to dismiss a false alarm easily, by shaking their breathing apparatus. Only in cases when they cannot move at all, a relatively direct indication that something has gone wrong, they cannot control the alarm. In that case the independence gets broken and the audible alarm can be heard by others and supports them post in MONITORING that something has gone wrong and in tracking the team's location.

As the study with the developers indicates, the pattern language also works as a rationale to shape future visions of technology design. For all four technology concepts, developers discussed the design and its interaction with the existing practice, they suggested a number of changes and areas for further research.

Second, a pattern language provides a description of the practice, as a means to access aspects of the practice that have not yet been supported by design.

The idea of identifying unsupported aspects of the practice for design by pattern languages has been proposed by Crabtree et al. (2002: 269).

In the design projects, the discovery of MASH-UP and MULTIMODAL ACTS changed the overall design concept in such a way that the novel technology can be combined with the environment and can be used in a variety ways, as suggest by the patterns. These practices had not been considered by the initial design. Interestingly, these patterns, once described, are not complex to understand or difficult to find in the ethnographic data. They are, nevertheless, easily to be overlooked when thinking about technical solutions for practice problems, as they are not explicit in regulations or training materials. The pattern MASH-UP allowed 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 help the firefighters to locate a beacon. Here, solutions for problems already present in the practice inspired the design directly.

Additionally, the designer can derive questions from the language that inspire new designs such as: Can we create systems that follow the overall concept of FLUID ORDER? How can ubiquitous computing build on the concept of INDEPENDENT UNITS and make firefighters' work easier without breaking the flexibility that they currently have? Can ubiquitous computing systems help frontline firefighter to TAKE GOOD CARE? How can we increase the abilities for MONITORING while keeping INDEPENDENT UNITS intact? What computing tools allow for MASH-UP in environments that are often unstable and hard to predict? What does it mean to design for a team that forms a BIG FAMILY and how can digital tools reflect this bond and culture? Can we enhance THE WAY BACK and what about supporting a BACKUP TEAM on its search for missing comrades? Can ubiquitous computing tools be open for a variety of uses and become HANDY MULTI TOOLS despite the intrinsic complexity of computing technology? What are right methods to evaluate and design technology given the great emphasis on EXERCISE, and the consequence that first time technology encounters may not necessarily reflect long term adaptation? Can we design tools to specifically support EXERCISE and connect with the concept to LEARN BY MISTAKE?

Answers to these questions do not need to suggest an obvious replication of features of the practice into designed artifacts; this translation can be more indirect.

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. Therefore the pattern language is more than a mere collection of patterns. The connection and interdependence of patterns allows to understand the overall configuration. During the design, maintaining balance, at a new stage of evolution, becomes a central concern.

While a technology design is usually often focused on solving a particular aspect of a practice, with a defined set of requirements, the pattern language provides the larger context for the artifact. With the pattern language, maintaining an overall balance, becomes a central concern during the design process, the solution to a problem receives a context.

The pattern language defines the overall configuration through both, the patterns and the links between them. Alexander, for his pattern approach, already stated: "the links between the patterns are almost as much part of the language as the patterns themselves" (Alexander 1979: 314) and argued that the structure of a pattern language "is created by the fact that individual patterns are not isolated" (Alexander 1979: 311), it "makes sense of individual patterns, because it anchors them, and helps make them complete." (Alexander 1997: 315) For the pattern language presented in this thesis this holds true as well. A pattern such as **RIGID STRUCTURE**, while coherent in itself, only works in combination with **INDEPENDENT UNITS**. **INDEPENDENT UNITS** then again calls for the pattern **MONITORING**.

In the design projects, the initial system built on selected aspects of the practice to support the firefighters. **MONITORING** and **THE WAY BACK** drove the 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 the reaction to unforeseen events. This balance, summarized as **FLUID ORDER**, explains how firefighters successfully handle the complexity and dynamic of the situation on the frontline. Supporting this balance by having both procedural and open aspects present in the design is therefore key in designing interactive systems for frontline firefighters.

In interviews with the developers, they also followed the approach to analyze the proposed technologies under the lens of the overall language. Often, they argued that while a certain technology might support one pattern, it interferes with another pattern. Technology became part of an overall configuration and was not only expected to target a specific aspect. Important here is that while a certain technological concept may seem to directly support a certain pattern, only the overall language brings about a perspective that allows to discuss and understand the side-effects that this certain technological proposal may have for other aspects of the practice.

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 technology, the pattern language approach highlights the existence of a larger social configuration, in which the technology will reside.

In the design projects, the initial focus on the problems that firefighter have in finding THE WAY BACK, remained a motivation, but was not the key driver for the later design; existing practices become a resource to learn from and to amplify. Instead of focusing on the problem of isolated INDEPENDENT UNITS the new design recognizes their importance in the overall configuration. The 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.

7.3 Future Work

Future work that builds on this thesis may design ubiquitous computing systems for frontline firefighters and bring about understanding of how to inject a pattern language into the design process.

Having clarified the purpose of a pattern language in the design process, there are a number of topics to be addressed by future research and design.

The most straightforward path for work to built on this thesis, would be to take the pattern language and make it part of a ubiquitous computing design project for frontline firefighters. The language can help to inspire and to review design proposals, to evaluate different design options or to understand why certain systems are successful or fail. The relation between the process of system design and the pattern language could become a topic of research and would add to the contribution of this thesis.

Here, the study with the developers, is only a first step. Having the pattern language available at the beginning of a new design project would allow studying its role in the communication between designers and users. Such setting would also allow to learn more about the impact of the pattern language by comparing different groups of users and designers who do or do not work with the pattern language. Additionally, such design project could also help to define, in interaction with users, how and to what extend the identified patterns can or should be evolved or changed when introducing new technology.

Such ubiquitous computing design project would, however, not only help to further test and detail patterns and their interaction with designed artifacts but also could provide a methodological learning on how to best inject such a language into a design process. With such study, this methodological approach could then also be more easily extended to other fields and thereby form a bridge between ethnographic work and design, an issue that, currently, is an open question in the HCI community.

For social or management science future work could integrate the results into research on how organizations handle safety-critical emergency situations.

Letting alone design-oriented research or development, the pattern language presents how firefighters organize their frontline work. For social sciences, the insights into the practice might become relevant for research focused on studying organizational settings. From an ethnographic standpoint, or one focused on managing science, the description of the firefighting frontline practice in the pattern language can be compared with other work settings that share certain aspects such as the time criticalness or the need to work in hazardous environments.

For firefighters the role and relevance of the pattern description for and beyond technology design projects, remains a topic for future research.

While there has not been extended research of the potential uses of the pattern language for firefighters in this work, some initial feedback of firefighters points to interesting aspects for future research. Whether directly due to the introduction of new technology to frontline firefighting or due to other changes, firefighting practice will evolve.

Reviewing the language, a firefighter of the fire service institute noted that the language provides an excellent representation of the work on the frontline that, however, could benefit from further extension. Recently, he argued, their firefighting school is working on also taking into account the psychological load of frontline workers working in emergency situations. For this aspect, he could see another emerging pattern that would describe how to handle the social and psychological side of emergency response work. Another type of extension of the language could include other stakeholders such as emergency response organizations and the people in need.

In addition to this extension of the language, his other comment was that frontline firefighting is only one part of firefighters' daily work. Other emergency response services provided by firefighters can also be described in order to provide an extensive overview of the practice.

Beyond frontline firefighting and safety-critical work, this research left open if the pattern language can be applied for other domains, too.

As introduced in the related work section, Erickson (2000a, 2000b) suggests pattern languages as a 'Lingua Franca' for all stakeholders in the design process. He calls for site-specific languages to be developed first that together can evolve into a general 'Lingua Franca'.

Following this line of thought, the question is if and to what extend the pattern language of frontline firefighting, overall or in part, can be applied to other domains. Research, on the one hand, can compare the language of frontline firefighting with languages developed for other domains, or, on the other hand, start by transposing the concepts presented for frontline firefighters to other domains. The question is also, whether the patterns could be described or grouped in more abstract terms.

Beyond the contents of the language, future design research can enhance the methodological understanding of using pattern languages.

This thesis has made use of Alexander's work by building a pattern language of human activity and following Alexander's original aim to learn about environments that are good, in all the possible meanings of the word.

As described in the introduction, the close interaction of computing artifacts and human practice is relevant beyond firefighters and safety critical work. Public spaces and private environments, people in their homes, at work and on the go–ubiquitous computing currently enters all these spaces. These spatial configurations relate to people's lives and are relevant for the design; they could be described in forms of pattern languages.

Interestingly, in these spaces, ubiquitous computing often closely relates to and is embedded in the physical configuration formed by architects. As computers go into the wild, like buildings, they are ever-present and shape our daily environments. The pattern language approach then may serve as a tool for architects and interaction designers alike. Thereby the original pattern language approach applied in this work to the field of computing systems would return to its original, architectural roots.

An open question is also how the interpretation of Alexander's work, as applied in this research, is relevant to the differing approach of using patterns to share design solutions. Especially for interaction designers who use patterns as means to share design solutions, this research leaves open the question, if and how they can build on Alexander's concept of the living structure, all the way down, to the small details of a human-computer interaction.

While in this work, I was driven by the challenge of designing computing systems that pervade our lives, designers, are often confronted with social configurations when creating artifacts. Architecture and urban planning, interior, product or service design, all of these disciplines are designing for and within existing social configurations. Here, adaptations of the pattern language approach to the special setting of these disciplines could help to handle the complexity of social configurations.

Here, also, a systematic comparison of the approach with other methods would provide new insights into the specific benefits of the pattern language approach. Methods to compare the pattern language approach with could be closely related to the approach such as pure grounded theory and affinity diagrams, or be more distant, such as the use of personas in design processes. Beyond a mere comparison, understanding the pattern language approach in its interaction with other design methods (e.g. (Sleeswijk Visser 2009)) would help designers to integrate the approach into their daily practice.

Finally, when converting and applying the pattern language approach in an industry context, the question arises, if and how the lengthy process or creating a pattern language followed in this work can be condensed.

Creating the pattern language for frontline firefighting has been a lengthy process. An industry context often does not have the time and resources to follow the same process. Consequently, the question is to which extend pattern languages can be created in shorter periods of time and with less resources.

8 Conclusion

The pattern language transforms the existing frontline practice into a design space for ubiquitous computing support; the approach is relevant for design processes apart from burning buildings, too.

The pattern language is a means to capture the social configuration of frontline firefighting and describes how firefighters successfully cope with the hazardous work environment.

I have started this work by arguing that for the design of ubiquitous computing for frontline firefighters we need to zoom out from accidents to overall configurations. As current research shows, designing ubiquitous computing systems is a sensitive endeavor that needs to respect local values and existing practice. Designing meaningful systems requires a situated perspective that takes into account the overall complexity intrinsic to frontline firefighting practice.

The challenge of understanding frontline firefighting gets amplified by its distance from our daily experience. The challenge becomes visible in current design research on frontline firefighting technology and the limited acceptance of proposed systems. Both aspects underline the call for a thorough understanding of the overall configuration of frontline firefighting.

With this call in mind, I was excited to learn about Alexander's work who argues that "the environment will come to life for us if, and only if, it is built from generating relationships inherent in the acts of our daily life." (Alexander 2009, 00:27:06ff) Architecture and interaction design seemed to face the same issues. Alexander's proposal of identifying patterns and Erickson's (2000a) proposal to apply this concept to connect ethnography and interaction design informed this research and pointed into a direction of how to address the need for a situated understanding of the practice.

Despite these proposals, I, nevertheless, remained doubtful. Will I actually find patterns? How can I find them? How will they relate? Is the pattern language indeed a relevant tool for the design process? Questions that were open in the beginning. Grounded theory and action research helped to understand and solidify Alexander's methods. And gradually, while applying these methods in the field studies with the firefighters and during analyses, patterns and the language began to emerge.

The change experiments, during which I introduced novel computing artifacts to the frontline and observed the effects, triggered a number of reactions from the firefighters. They described the contrast between their normal work practice and the concepts embedded in the designed artifacts. The empathic exercises not only allowed me to get an insiders perspective, they also formed a bond with the firefighters that set a foundation of trust for formal ethnographic work and informal talks about the work at the firehouse, where especially the latter revealed aspects and the small nuances that might not be formally defined, yet constitute important aspects of the work. Combining the results from all studies, grounded theory allowed me to complete the pattern language.

In the introduction of this work, I have asked the research question how frontline firefighters successfully cope with the hazardous work environment that they are confronted with. The pattern language provides answers. It shows that a number of aspects create an overall balance. Clear hierarchies, roles and procedures allow for immediate, fast action and are as important as the open spaces and improvisational elements that support firefighters in dealing with the unforeseen in an ever-changing environment.

The pattern language has shown to be a relevant tool to reflect on and inform design processes.

In the introduction, I have also asked the question how this existing frontline practice is influenced by ubiquitous computing technologies and what we can learn from the interaction between new technologies and existing practice for the design of future ubiquitous computing systems.

For the design projects, the pattern language allowed to rationalize the different design proposals for navigation concepts, one that is inspired by MONITORING, the other driven by a number of aspects to support INDEPENDENT UNITS.

The workshop with the developers, while small in its scope, provides indicators that developers can use the language to speak about the social dimension of ubiquitous computing systems for frontline firefighters. It supports the claim that the pattern language indeed supports a phase of "reflective thought and conceptual analysis" (Harper et al. 2008: 59), it allows to "expand the frame, to metaphorically zoom out to a wider view" (Suchman 2007: 283-284), it poses questions about "what it means for a system to be 'good' in a particular context" (Harrison et al. 2007), it sets a context for the systems to be designed. Alexander's and Erickson's proposal of using pattern languages to support design has shown to be a handy framework for connecting ethnography and design.

The pattern language, however, is not to be confused with a dogma or 'Sachzwang,' as Rittel (1976) called it. It is a theory that stems from snapshots of current frontline firefighting practice in firefighting organizations from two countries. While firefighting is part of a framework of regulations and training and thus not very likely to change dramatically, especially new technology has the potential to drive the evolution of the practice and make firefighting different from what it is today and thus different from what is described in the pattern language. Therefore, by using the pattern language to support their designs, technology designers may be inspired by the existing practice and aim for adopting the existing structure, they should, however, also be change agents and, in collaboration with firefighters, aim for gradual transformation.

While the pattern language presented in this work contributes to the endeavor of structure-preserving transformations for the introduction of ubiquitous computing for frontline firefighters, the approach is relevant for design apart from ubiquitous computing and burning buildings, too.

The problem that I have addressed with this work might appear very specific. Designing ubiquitous computing for frontline firefighters might not be an everyday activity. On a more abstract level, the problem tackled here is, however, not limited to the domain of firefighting. Bringing novel computing devices into existing social configurations is a much more general problem. Weiser's (1991) vision of ubiquitous computing currently drives research and commercial efforts in a great variety of fields. And beyond computing technology, designers are confronted with social configurations when creating new services and artifacts. Learning about existing configurations and applying Alexander's concepts of pattern languages and structure-preserving transformations, therefore, holds relevance for other domains, too.

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