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Leveraging sensing-based interaction for supporting reflection at work: the case of crisis training

Thesis for the degree of Philosophiae Doctor

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Abstract

Continuous training for preparedness empowers crisis workers (e.g. firefighters, paramedics) to achieve better performance and commitment in providing help to the communities struck by a nature or human-caused crisis. To achieve these goals the body of research in reflective learning provides theoretical tools to guide data-driven, collaborative reflection on work experience towards changes in behaviour. ICT support for reflective learning facilitates the process by providing technologies for capturing work experience, visualising discrepancies as reflection triggers; and by supporting sharing of learning outcomes. Yet current ICT tools do not consider the very specific, situated nature of crisis work. While data capturing tools lack interaction paradigms suitable for being used during work, visualisation tools struggle in providing the user with the context information needed to ground reflection on past work experiences and to achieve learning outcomes that are structured to be easily shared among colleagues.

The research in this thesis investigates how theory in the field of embodied and sensing-based interaction can inform the design of computer interfaces to better assist reflection practice in the case of crisis training. This thesis explores how conceptual tools from reflective learning theory can be implemented in technology tools to make the capture of work experience lightweight and pervasive, and interaction with reflection-useful information tangible, situated and playful.

The work is grounded on design science methodology. Six field studies have been performed during large physical simulations of crisis work. Exploratory studies drove eight design iterations of sensing-based interfaces. Software and hardware rapid prototyping techniques, open source and digital manufacturing tools have been largely employed. Prototypes were eventually returned to the field and tested against acceptance, usability and impact on learning. Results from evaluations were used to validate existing theories and for the development of new constructs. Commercial exploitation of the research outcomes are being discussed.

The resulting contributions add new knowledge to guide the design of novel sensing-based interfaces to support continuous training of crisis workers. To this end, it is demonstrated how conceptual tools from reflective learning theory can be mapped to technology to support the *capture*, *re-creation* and *generation* of work experience. Seven challenges to drive the design of experience-capturing tools are provided. The challenges shed light on *what* information is relevant and *how* to capture relevant information and they were explored with the production of prototypes of wearable data capturing tools. Further, the thesis contributes with novel techniques derived from sensing-based interaction. The paradigms have been implemented in embodied user interfaces to reduce distraction while *capturing* experience at work, to allow for *re-creating* past experience situated in a physical context that provides prompts for reflection; and to allow *generating* engaging and collaborative work experience by means of serious games. Building prototypes of such user interfaces requires a wide range of competencies in software and hardware engineering. Lessons learnt from the author's experience provide knowledge for the creation of designer's tools to ease rapid prototyping of sensing-based interfaces.

Preface

This thesis is submitted to the Norwegian University of Science and Technology (NTNU) for partial fulfilment of the requirements for the degree of philosophiae doctor.

The main body of doctoral work has been performed at the Department of Computer and Information Science, NTNU, Trondheim. Professor Monica Divitini has been the main supervisor and Babak Farshchian has been the co-advisor.

Part of the research work was done during academic visits to foreign institutions: the City London University, under the supervision of Professor Neil Maiden; and the Massachusetts Institute of Technology, under the supervision of Professor Carlo Ratti.

This doctoral work is co-funded by “MIRROR Reflective Learning at Work”, a research project within the EU-ICT 7FP programme.

Acknowledgments

Foremost, I would like to express my deepest gratitude to my supervisor Professor Monica Divitini and co-advisor Associate Professor Babak Farshchian. Your guidance and precious advices made me a better researcher and a better person. Your support and trust, always present throughout my PhD journey, make me proud. You have been an example for me, I cannot think of better supervisors to have.

I wish to thank former and current colleagues that have contributed in many ways to my work: Birgit, Ines and Alessandro for co-authoring some of the papers, Emanuele for helping with the prototyping work; my officemates Elena, Francesco and Hans for the coffee-breaks.

I extend my gratitude to other members of the Department of Computer and Information Science for their opinions and insights; and the staff of NTNU Technology Transfer AS, in particular Marit, Silje and Kjetil, for bringing their perspective and ideas into my research. I also thank Stewart Clark for editing Part I of this thesis.

Taking part to the MIRROR project has been essential to achieve the research goals reported in this thesis. I thank all the consortium members for the productive discussions, especially Regola s.r.l and Mr. Gianni della Valle for arranging the field studies this research work builds on.

During part of my PhD training I was honoured to be a guest in two foreign institutions. I thank Professor Neil Maiden at the City London University for his supervision, and colleagues and friends Anja, for the teamwork; Dara, Graham, Milena, Minou, Mobina and Jacques for taking part to the evaluation of prototypes. I'm grateful to Professor Carlo Ratti at the MIT SENSEable City Lab for his lead; and colleagues and friends Professor Paolo Santi, Professor Rex Britter, Aldo, Alice, Anthony, Chris, Clara, Kris, Luis, Matteo, Matthew, Miriam, Newsha, Pierrick, Ricardo and Remi for their amazing work.

I am indebted to all my friends who have supported me over the last few years, those here in Norway and those in Italy. Thanks for being always there for me.

Finally, I want to express my affection to my awesome family: Lucia, Mario, Martina and Stefano, Antonella, Corrado and Federica; grandparents Benedetta and Costante. Without you all of this would not have been possible, *thanks*.

Simone Mora
February 26th, 2015

Contents

List of Figures

List of Tables

Abbreviations

NTNU Norwegian University of Science and Technology

MIT Massachusetts Institute of Technology

ICT Information Communication Technology

CSRL Computer Supported Reflective Learning

TEL Technology Enhanced Learning

ISCRAM Information Systems for Crisis Response

TEI Tangible, Embedded and Embodied Interaction

DOFI Declaration of Invention

HCI Human Computer Interaction

WIMP Windows Icons Mouse Pointers

GUI Graphical User Interface

TUI Tangible User Interface

MCRit Model Control Representation intangible tangible

MVC Model View Controller

MAR Mobile Augmented Reality

CAD Computer-Aided Design

Part I

Introduction and methods

1 Introduction

1.1 Problem statement

This thesis is about how to improve crisis training with ICT systems. Crisis training is an umbrella term for complex, collaborative activities aiming at improving people's ability for *preparedness* to human and natural-caused crises (e.g. a flood or a terrorist attack) (Lagadec 1997). The term *crisis* refers to a sequence of problematic events that, if left unattended, might eventually lead to a *disaster*, causing huge damage and loss of lives. Disasters have a huge impact on societies, both in terms of human beings and costs. Over the last 35 years, the frequency of disasters has increased five-fold; the damage caused has multiplied approximately eight times[1]. According with the United Nation Office for Disaster Risk Reduction, over the decade 1992-2012, disasters have affected 4.4 billion people and have caused USD 2 trillion in damage worldwide[2]. For this reason training for better crisis management is a priority for many countries, including those in Europe.

Crisis training focuses on teaching emergency workers (e.g. firefighters, paramedics) how to efficiently respond to a crisis; for example by actuating coping strategies and implementing rescue procedures (crisis management). Each crisis is likely to be a specific, unpredictable event that will not take place again under the same circumstances. Training for crisis preparedness is a wicked problem, however better crisis management can positively affect everyone's lives.

There are four main approaches to crisis training: protocol training, tabletop exercises, physical simulations and serious games; on top of that real crises also offer triggers for learning (Deverell 2009). In this research work we look at medium to large scale physical simulations and serious games as key training practices; aiming at advancing them with technology. Physical simulations recreate at best real crises in terms of environment (e.g. presence of debris, collapsed buildings), and in reproducing feelings experienced by crisis workers such as stress, tension, time pressure and uncertainty (Borodzicz and Haperen 2002). Yet they are determinated by high set-up cost and the large effort required to coordinate multiple organisations and dozens of field workers. Moreover it has been observed that the impact of those

[1] Source: "Council adopts new Union Civil Protection Mechanism"
Available at: www.consilium.europa.eu/uedocs/cmsdata/docs/pressdata/en/jha/140108.pdf

[2] Source: The United Nation Office for Disaster Risk Reduction (http://unisdr.org)

events is limited by lack of technologies, for example to capture data and maintain an overview of rescue efforts (Kyng, Nielsen and Kristensen 2006). Otherwise, serious games trade the realism of physical simulations to provide a more lightweight training experience which can be easily reproduced frequently by single workers or teams. The "fun" element typical of games is added as motivator to engage workers in frequent play. In this perspective physical simulation and serious games are are not mutually exclusive but rather complementary approaches to crisis training, providing realistic training experiences.

The research in this thesis investigates how to maximise crisis training learning outcomes during physical and serious game-based simulation of crisis work. It is based on the assumption that training practices already in place can be enhanced by combining (i) reflective, experience-based learning approaches and (ii) advances in ICT and sensing-based interaction (Zhai and Bellotti 2005).

Experience-based learning is a powerful tool. Facilitating learning from work experience of the different roles in the field (e.g. disaster managers vs. field workers) can bring outcomes to complement traditional formal training. Learning from experience entails reflection (Boud, Keogh and Walker 1985; Dewey 1998; Kolb and Fry 1974). Reflection on action has been a research topic since the work of Dewey (Dewey 1933) that describes how we learn by comparing our expectations to new and past experience. Reflecting on action is critical in order to learn from past experience with the goal of performing better in the future (Boud, Keogh and Walker 1985; Schön 1983); and a number of tools have been developed to support reflection, as an individual or collaborative activity. Among those, the CSRL (Computer Supported Reflective Learning) model developed as part of the MIRROR project[3] aims at providing guidelines to develop technology tools to support reflection. It identifies a cycle of four stages of reflection (Krogstie, Prilla and Pammer 2013): *do work*, *initiate reflection session*, *conduct reflection session* and *apply reflection outcomes*. For each stage a number of reflection-useful activities that can be augmented with technology are provided.

In the context of crisis training, reflection activities can be summarised in three areas: (i) capturing work experience, (ii) re-creating work experience and (iii) generating realistic work experience. Technology provides help in different ways. Sensors can capture aspects of real or simulated work experience, including qualitative and quantitative elements; data which can be visualised on a interactive computer interface to provide triggers for re-evaluating an experience towards a learning outcome, or that can be used to plan new training work. Yet current ICT tools do not consider the very specific, situated nature of crisis work. While data capturing tools lack interaction paradigms suitable for being used during work, visualisation tools struggle in providing the user with the context information needed to ground reflection on past work experiences and to achieve learning outcomes that are structured to be easily shared among colleagues. Moreover the introduction of technology is impeded by resistances in organisations that might be reluctant to modify accustomed practices, even if unproductive (Comfort 1993).

[3]MIRROR Project - www.mirror-project.eu

Theories in the field of *sensing-based interaction*, can inform the design of novel technologies to better assist reflective learning in crisis training. Sensing-based interaction is a trend in HCI which promotes sensing information to make human-computer interfaces, sensing-based interfaces, more effective (Zhai and Bellotti 2005). *Tangible* and *embodied* (Dourish 2001) are two characterising traits of such interfaces. They aim at enabling interaction with digital information exploiting the affordances that everyday objects provide, rather than traditional paradigms such as keyboard, mouse or touchscreens. Using sensor-based technology, conventional objects can be augmented and turned into “physical handles” for digital operations (Ishii and Ullmer 1997), linking their traditional affordances to new digital meanings. Making interaction with computers more “physical” allows for leveraging humans' skills for interaction with the real world (Shaer and Hornecker 2009). This approach might be well suited for crisis fieldwork which, contrarily to traditional office work, has a strong physical and spatial connotation. In this perspective, tangible and embodied interfaces have been successfully employed to provide natural (Terrenghi et al. 2005) and situated (Klemmer, Hartmann and Takayama 2006) learning and increased reflection and engagement (Rogers and Muller 2006). “Being able to move around in the world and interact with pieces of the world enables learning in ways that reading books and listening to words do not”. (Klemmer, Hartmann and Takayama 2006)

Yet building prototypes of sensing-based interfaces, is a complex task which requires scientists to master a wide set of skills including product design, hybrid software and electronics development, as well as hardware construction and assembly. This is still a relatively new area in HCI and it is characterised by the absence of a widely established toolchain to help the prototyping work. Rather, it is characterised by fast adoption of edging technologies and a pragmatic attitude at *tinkering* and *thinking-thrugh-prototyping* (Klemmer, Hartmann and Takayama 2006). Considering the essential role of prototypes in the development of novel technology; developing a skillset to enable rapid prototyping of hybrid software/hardware artefacts is essential to the accomplishment of the goals sought by this PhD work.

1.2 Research methodology

The work in this thesis is based on *design research* (Hevner and Chatterjee 2010; March and Smith 1995). The work followed a *user centred approach* (Maguire 2001; Gulliksen et al. 2003), based on exploratory studies and design work in multiple iterations.

Several qualitative research methods (Robson 1993) have been adopted, including shadowing and observation of crisis worker during field studies. Scenarios, personas and mockups aided the user-centred design work. Consistently with design research methodology, grounded on the activities of *building* artefacts for a specific purpose and of *evaluating* how well the artefacts perform (March and Smith 1995), a number of prototyping iterations and evaluation studies have been performed.

Prototyping involved the construction of sensing-based interfaces to support re-

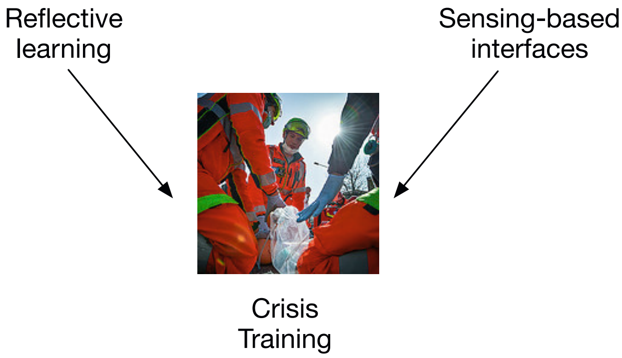

Figure 1.1: Relation among the three domain of this thesis

flection processes. The design of prototypes was grounded in field studies during physical simulations of crisis that I attended. Simple prototypes were initially used to build a deeper understanding of the crisis domain, where I did not have any previous knowledge. They acted as technology probes (Hutchinson et al. 2003) and facilitated building and understanding of the crisis domain by engaging users in focus groups. Later, multiple iterations implemented a growing set of requirements in fully working prototypes that were robust enough to be deployed during simulated crisis work.

User evaluations followed each design iteration (Figure 1.2). The aim was both to assess usability of the prototypes and impact on reflection outcomes. Prototypes were evaluated both during focus groups and during large simulations of crisis response work. Results from evaluations have fed the following design iterations, and contributed in the validation of theories on reflective learning and into the development of new constructs.

1.3 Research questions

The main research question for the PhD work is:

> MRQ: What are the opportunities introduced by combining reflective learning theories with sensing-based interfaces for supporting crisis training?

To answer the main research question the work has been broken down into three sub-questions:

> RQ1: How sensing-based interfaces can be designed to enable unobtrusive experience collection during crisis work?

Figure 1.2: One of the evaluation field studies performed

> RQ2: How sensing-based interfaces can be designed to trigger and support reflection activities?

> RQ3: How sensing-based interfaces for supporting reflection can be rapidly prototyped?

While the first two questions aim at investigating the design of systems to provide technology support for the tasks of *capturing*, *re-creating* and *generating* work experience; the third question investigates how toolkits and open-source communities can ease the implementation of design ideas into prototypes.

1.4 Research outcomes

There are three main outcomes for this PhD work.

Seven research papers published in peer-reviewed conferences and journals explored the research questions.

Building on results reported in the papers, a body of knowledge contributing in the fields of Technology Enhanced Learning (TEL), Information Systems for Crisis

Response (ISCRAM) and Tangible, Embedded and Embodied Interaction (TEI) has been developed.

Finally research contributions have been evaluated for commercial exploitation. Five *Disclosure of Invention (DOFI)* have been filed for technology transfer and early contacts with the industry have been established.

1.4.1 Research papers

The research questions RQ1-RQ3 are addressed in the following research papers:

P1: Mora, S., Boron, A., & Divitini, M. (2012). CroMAR: Mobile Augmented Reality for Supporting Reflection on Crowd Management. *International Journal of Mobile Human Computer Interaction*, 4(2), 88–101.

P2: Mora, S., & Divitini, M. (2014). Supporting Debriefing with Sensor Data: A Reflective Approach to Crisis Training. *In Proceedings of Information Systems for Crisis Response and Management in Mediterranean Countries, ISCRAM-MED*, 196(7), 71–84.

P3: Mora, S., & Divitini, M. (2014). WATCHiT: a modular and wearable tool for data collection in crisis management and training. *In Proceedings of the European Conference in Ambient Intelligence, AMI*, 8850(22), 274-289.

P4: Di Loreto, I., Mora, S., & Divitini, M. (2012). Don't Panic: Enhancing Soft Skills for Civil Protection Workers. *In Proceedings of International Conference on Serious Games Development Applications, SGDA*, 7528(1), 1–12.

P5: Mora, S., Di Loreto, I., & Divitini, M. The interactive-token approach to board games. *Ready for submission.*

P6: Müller, L., Divitini, M., Mora, S., Rivera-Pelayo, V., & Stork, W. (2014). Context Becomes Content: Sensor Data for Computer Supported Reflective Learning. *IEEE Transactions on Learning Technologies*, PP(99).

P7: Mora, S., & Farshchian, B. A. (2010). A Unified Architecture for Supporting Direct Tag-Based and Indirect Network-Based Resource Discovery. *In Proceedings of the International Conference on Ambient Intelligence, AMI*, 6439(20), 197–206.

Table 1.1 shows the mapping between research papers and research questions. In addition to these papers, this PhD work has produced seven secondary conference papers. These works present incremental achievements in research that have added to the investigation of the research questions. Abstracts of the papers are included in Appendix A.

Table 1.1: The relation between research papers and research questions

Research questions		P1	P2	P3	P4	P5	P6	P7
RQ1	How sensing-based interfaces can be designed to enable unobtrusive experience collection during crisis work?		•	•			•	
RQ2	How sensing-based interfaces can be designed to trigger and support reflection activities?	•	•		•	•	•	
RQ3	How sensing-based interfaces for supporting reflection can be rapidly prototyped?			•		•		•

1.4.2 Research contributions

The seven papers published added to the following contributions.

> ***C1:*** *Implementation and evaluation of MIRROR Computer Supported Reflective Learning (CSRL) theory.* It includes a validation of previous theoretical models and the formulation of new constructs.

> ***C2:*** *Knowledge about designing experience-capturing tools for crisis workers.* It defines the design space as well as design challenges for building computer-based data capturing tools.

> ***C3:*** *Novel sensing-based interaction techniques to support re-creation and generation of work experiences in crisis training.* It describes novel sensing-based interfaces for the visualisation and manipulation of data captured from work experience.

> ***C4:*** *Knowledge about implementing prototypes to be deployed into the wild.* It presents challenges and lessons learnt derived from the author's experience in building prototypes of sensing-based interfaces.

The relation of research papers with respect to the research contributions and communities is represented in Figure 1.3

1.4.3 Towards exploitation of research

During the final phase of the investigation, commercial exploitation of research contributions has been investigated. The focus was on assessing efforts needed and path of actions to evolve the prototypes developed as theory demonstrator into commercial products. To this end, I co-authored five *Disclosure of Invention* (DOFI): technical documents that capture the description of the technologies created and establish inventorship. DOFIs were drafted based on information published in research papers (Table 1.2)

Table 1.2: The relation between registered inventions and research papers

	Authors	Invention	Research papers
I1	Mora, S., Boron, A. and Divitini, M.	CroMAR. Situated reflection and training in crisis management	P1, P2
I2	Mora, A. and Divitini, M.	WATCHiT. Wearable data collection in crisis management and training	P2, P3
I3	Di Loreto, I., Mora, S. and Divitini, M.	"Don't Panic!" A serious game for enhancing soft skills for Civil Protection workers	P4, P5
I4	Mora, S., Di Loreto, I. and Divitini, N.	Anyboard: a platform for creating and play digital board games	P5
I5	Mora, S. and Divitini, M.	TILES Toolkit. Building seamless interfaces between people and the Internet of Things	P3, P5

Disclosure of inventions were filed at the NTNU Technology Transfer Office[4], a business incubator affiliated with NTNU, and in accordance with Norwegian law[5]. They were used by technology transfer managers to assess patent applicability and establishment of commercial activities. To this effort, I presented the research outcomes to several representatives from the industries working in the emergency management field, raising positive and supportive feedbacks. In November 2014 I was granted by NTNU Discovery [6] a NOK 150.000 (about USD 22.000) seed fund for financing further commercial exploration of the research results after the PhD completion.

[4]NTNU Technology Transfer AS - www.tto.ntnu.no
[5]In accordance with "Act respecting the right to employees' inventions 17.4-1970", and NTNU's internal Guidelines for innovation
[6]NTNU Discovery - http://ntnudiscovery.no

1.5 Context of the work

The research presented in this thesis is framed within the EU-funded (IST-FP7) project MIRROR[7]. The objective of MIRROR is to empower and engage employees to reflect on past work performance and personal learning experience in order to learn in "real-time" and to creatively solve pressing problems. MIRROR is to help employees to increase their level and breadth of experience significantly within a short time by capturing the experience of others.

As an associate researcher of MIRROR I took part in shaping the results of the projects by designing and implementing ICT systems, writing deliverables and attending project meetings. Thanks to MIRROR I cooperated with crisis worker associations to run field studies. I also benefited from discussions, joined works and co-authored publications with members of the consortium. After the project final review in September 2014, MIRROR has been graded as "Excellent" by the EU Commission.

During the PhD I was a visiting fellow to two foreign institutions: *City London University*[8] in London (UK), where I was supervised by professor Neil Maiden; and *MIT SENSEable City Lab*[9] in Cambridge, MA (USA), under the supervision of professor Carlo Ratti. The purpose of the two visits was to investigate whether the technologies developed during the PhD could be generalised to application domains outside crisis training. A summary of the activities performed as visiting fellow is provided in Appendix B.

I also co-advised the thesis work of eight master's students who have contributed to the development of prototypes. One of them co-authored P1.

1.6 Structure of the thesis

The thesis is composed by two parts:

- **Part I** presents the introduction to this work. It gives on overview of the background, the methods used, the results achieved and the contributions provided by the thesis.
- **Part II** contains the seven research papers that added to the results of this thesis

The rest of **Part I** is organised as follows:

- **Chapter 2** introduces the crisis domain providing an overview on scenarios, activities and roles; and presenting debriefing as a tool for reflective learning.

[7]MIRROR Project - www.mirror-project.eu
[8]City London University - http://city.ac.uk
[9]MIT SENSEable City Laboratory - http://senseable.mit.edu

- **Chapter 3** describes relevant background theory on reflective and experience-based learning with focus on describing the Computer Supported Reflective Learning model adopted as theoretical underpinning of this research work.
- **Chapter 4** presents relevant background theory in sensing-based interaction, motivating the use of that paradigm applied to reflective learning.
- **Chapter 5** depicts the research strategy and approach adopted by this PhD work, giving overview of the user studies conducted and prototypes built.
- **Chapter 6** summarises the results for the research papers.
- **Chapter 7** outlines the contribution of this thesis and their relations to the research papers.
- **Chapter 8** proposes an evaluation of the work done.
- **Chapter 9** concludes the thesis and sketches out future research and innovation work.
- **Appendix A** summarises secondary research papers that were written during the research fellowship.
- **Appendix B** outlines research done during academic visits in foreign institutions.
- **Appendix C** includes a benchmark of hardware toolkits for rapid prototyping which has been used to select the specific tools used to implement the prototypes in this PhD.

Part II contains the seven research papers in full length.

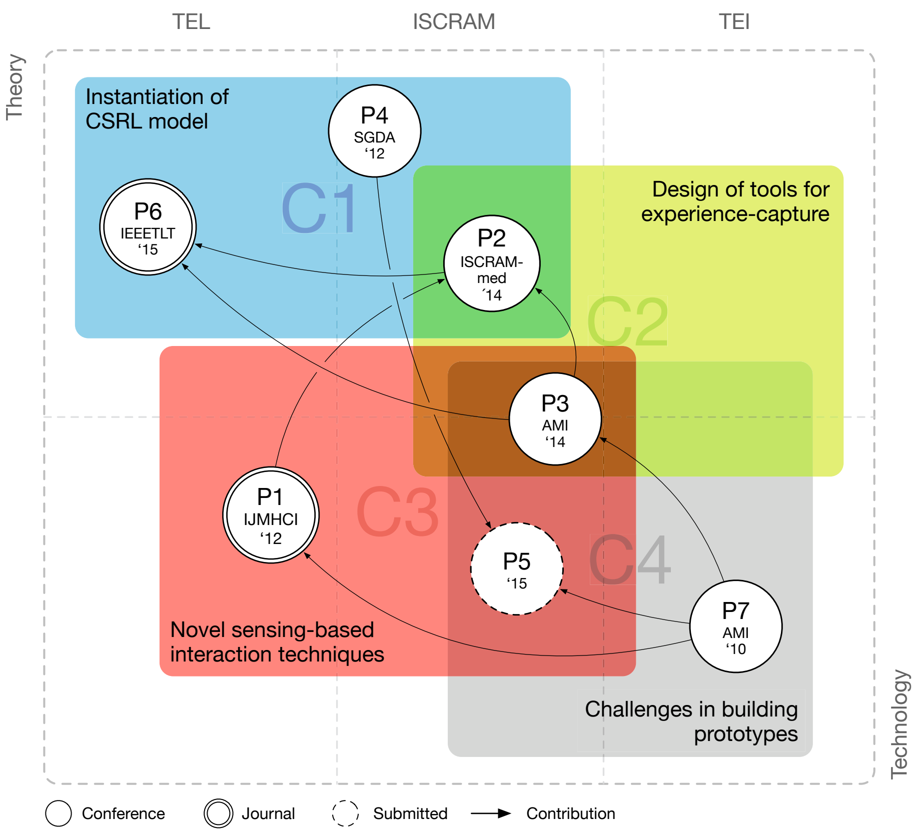

Figure 1.3: Research papers and the main topics of the research contributions

2 The case of crisis training

In this chapter I provide an overview on crisis *training*, *preparedness* and *management* activities, highlighting how reflection can improve learning outcomes. These three activities constitute a waterfall process, with training exercises aiming at making workers more prepared towards managing a crisis at best.

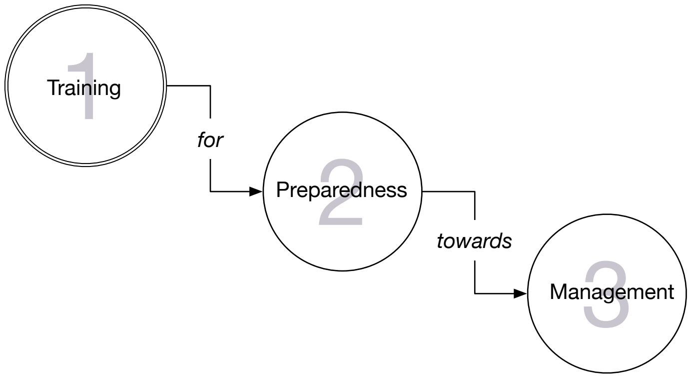

Figure 2.1: Three activities required to better deal with a crisis

2.1 Crisis management

The terms *crisis*, *emergency* and *disaster* are often used as synonyms. They deal with events that belong to the "un-ness" category: unexpected, undesirable, unimaginable, and often unmanageable situations (Boin and Hart 2007; Hewitt 1983). In this space made up of both foreseeable and unexpected elements, crisis management works at anticipating what can be predicted in order to minimise the unforseen[1]

In this thesis the term *crisis* refers to a single or sequence of problematic events that may lead to a dangerous situation, whether that is an *emergency* or a *disaster*.

[1]Source: http://emergency-planning.blogspot.it

While an emergency is an episode that requires immediate attention, but usually on a small scale, it can turn in a disaster if left unattended. For example expected heavy rainfall could lead to several emergencies (e.g. car crashes, flooded bridges) and might eventually turn into a disaster (e.g. massive flooding or a hurricane). Disaster can be caused by nature or humans and might or might not show early signals that allow the disaster to be avoided or mitigated. Disasters have a huge impact on societies, in terms of loss of human lives and costs. Over the last 35 years, the frequency of disasters has increased five-fold and the damage caused has multiplied by approximately eight times[2] Over the decade 1992-2012, disasters have affected 4.4 billion people and have caused USD 2 trillion USD in damage worldwide[3].

Yet, although crises are getting more frequent, people's ability to deal with adverse events, *crisis management*, is also growing (Boin 2009). Crisis management involves a set of collaborative inter and intra-organisation activities to respond to a crisis. Examples of typical roles and activities deployed are: police forces to constrain access to the crisis scene, firefighters to explore and map undisclosed areas, dog handlers to search for the injured, paramedics to activate triage and hospitalise the wounded; fellow citizens to report information and stay out of danger.

Activating effective crisis management strategies can avoid or reduce the extent of an emergency or a disaster, save human lives and reduce the cost of recovery. For this reason improving crisis management practices, hereafter *crisis training* is a priority for many European countries [4] Providing better crisis management is not easy task. This is due to the nature of crisis work as a complex, inter-organisational activity, often without a clear start or end, and involving many different roles.

2.2 Crisis preparedness

The effort of providing better crisis management is also known as *crisis preparedness*. It is a collective activity which involves fellow citizens, crisis workers and institutions at multiple levels. Getting prepared to a crisis is a continuous process focusing on two areas, *prevention* and *response* (Deverell 2009)

Prevention refers to activities aiming at avoiding a crisis; e.g. mitigating risks by monitoring the environment and raising awareness in the population about how to recognise early warnings.

Response is concerned with getting ready to promptly react when a crisis occurs, in order to be able to mitigate it so that there is as little damage as possible and to reduce its impact on the population. It includes activities related to protocol formalisation and training of crisis workers.

[2] "Council adopts new Union Civil Protection Mechanism"
Available at: www.consilium.europa.eu/uedocs/cmsdata/docs/pressdata/en/jha/140108.pdf

[3] Source: The United Nation Office for Disaster Risk Reduction (http://unisdr.org)

[4] "Council adopts new Union Civil Protection Mechanism"
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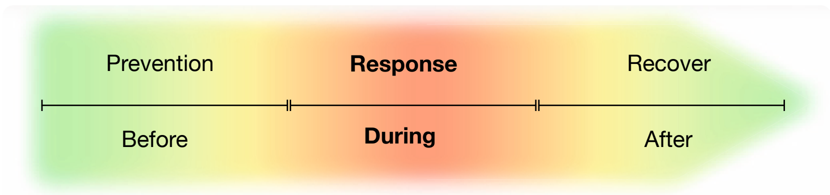

Figure 2.2: Phases of a crisis

Crisis workers are trained volunteers and professionals to provide help to the people in need; for example firefighters, police, paramedics. Training of crisis workers, hereafter *crisis training*, is a critical activity to improve crisis management because it deals with the ability of people to react to a crisis and reduce the risks of the same turning into an emergency or disaster. As matter of fact, previous research has shown that the outcome of a disaster is highly correlated with preparation and training prior the beginning of the crisis (Asproth, Holmberg and Löfstedt 2010).

Different approaches and activities related to *crisis training* are described in the next section.

2.3 Crisis training

Four approaches to crisis training have been identified: protocol training, tabletop exercises, physical simulations and serious games. They share the goal to produce learning outcomes towards better crisis management practice. The presented approaches are not mutually exclusive but rather complementary. They are the expression of a trade-off between adding realism to the training experience and costs (Figure 2.3).

Figure 2.3: Cost and realism in different training activities

Protocol training - It is a formal learning activity related to teaching of procedures, protocols and best practices. This is often the first type of training given to newcomers, e.g. by means of a crisis management course.

Tabletop exercises - Often performed at the strategic level, it usually involves disaster managers to gather together and talk through a simulated disaster. There is usually little realism in a tabletop exercise[5]: equipments are not used, resources are not deployed in space and time constraints are not introduced. Tabletop exercises usually run for a few hours, the limited scale of the exercises make them a cost-effective tool to validate plans and activities.

Physical simulations - They are large-scale events that try to recreate as much as possible events and context from real crises, in terms of environment, tasks and challenges, stress and emotions. Simulated crisis events can run for days, they take place on-location using, as much as possible, equipment and personnel that would be deployed on a real event. Simulations involve a wide range of roles from disaster manager, to team leaders and field workers. They are high cost events and for this reason are run sporadically; it is therefore important to maximise their training outcomes.

Simulations usually take place in remote areas unaccessible to the public, which are set up to recreate harsh conditions like the presence of debris, flooded terrains, fire ashes and broken cars. In this setting, volunteers impersonating the injured to be rescued are located in places undisclosed to the trainees (Figure 2.4-left).

Figure 2.4: Different phases of a simulation, setup (left), work (centre), debriefing (right). Pictures were taken during field studies performed by the author.

A typical training session includes *briefing*, *simulation* and *debriefing* phases. During briefing the esercise manager describes the settings, and assigns duties to the teams. During simulation workers implement rescue procedures (Figure 2.4-centre). The work involves cooperation among: police forces, to handle traffic and fence the operational area, firefighters to explore and secure undisclosed areas, civil protection workers to build field hospitals, dog handlers to search for survivors and teams of paramedics to activate triage, treat the injured and transportation to the nearest

[5]source: http://www.epa.gov/watersecurity/tools/trainingcd/Pages/exercise-menu.html

field hospital. A collaborative debriefing of the events, with focus on time of completion of procedures and issues that might have been arisen during the practice, concludes the simulation (Figure 2.4-right).

During this PhD work the author performed six field studies during physical simulations. A list of the studies and methods adopted is given in Chapter 5.

Serious games - They aim at teaching useful skills for crisis management leveraging the "fun" aspect of games as a motivator to play repeatedly and gain multiple perspectives. Rather than seeking to teach *hard skills* like protocols and best practices, serious games work best at enhancing *soft skills* e.g. communication styles, stress management and coping strategies (Sagun, Bouchlaghem and Anumba 2009). Those skills are useful both during prevention and during response to a crisis. Serious games bridge the gap between tabletop exercises and physical simulations: they are more realistic than the former yet without the huge costs of the latter. They can be played multiple times, both by individuals and collaboratively by teams. An ecology of serious games can address a variety of roles and tasks: being a lightweight training tool, each game can be tailored on a specific learning objective. Serious games for crisis training range from board game to highly immersive virtual environments, for a review see (Di Loreto, Mora and Divitini 2012a).

While the first approach presented relies on formal learning (e.g. classroom teaching), the other approaches can benefit from *reflective learning* (Kolb, Rubin and McIntyre 1984) techniques; being the training experience focused on doing some extent of real work.

2.3.1 Experiential learning, one of the sought-after outcomes of crisis training

Experiential learning is one of the sought outcomes of crisis training. It is an informal learning approach that makes use of work experience and reflection in order to achieve learning outcomes (Kolb, Rubin and McIntyre 1984). Although learning by experience and lesson drawing are still quite unexplored areas of crisis management (Lagadec 1997; Boin and Hart 2007; Stern 1997), the important role of *experience* in crisis training, as means for achieving organisational learning, is widely acknowledged.

Experience gathered during real and simulated crises can be used to achieve a learning outcome (Deverell 2009), which may occur "when experience systematically alters behaviour or knowledge" (Schwab 2007, p.233). Larsson (Larsson 2010) highlights how past experience (e.g. from an earlier training event) can hold knowledge useful for managing a new crisis for example to correct mistakes done in the past: "Personal and group experiences, together with exercises, seem to be the two most important forms of learning" (Larsson 2010, p.714). As stated by Hillyard (2000), "...learning together from an event in order to prevent, lessen the severity of, or improve upon responses to future crises". The correct action to take often can only be derived from experience, e.g. handling of the events in similar situations.

Yet, learning from crisis work experience is not easy. While learning during a crisis, or *intra-crisis*, is very difficult due to time pressure, stress and demands for rapid action (Deverell 2009) and because learning is typically a retrospective exercise (Jasanoff 1994); *inter-crisis* learning, before and after a crisis event, is also challenging. Moynihan (2008) identifies ten barriers to effective learning. Among those the high consequentiality of crises makes experiential learning costly (La Porte and Consolini 1991), moreover the specificity of each crisis event makes hard to apply learning outcomes from one crisis to another.

Therefore, how work experience can produce a learning outcome? And what are those learning outcomes?

Work experience can be turned into new knowledge thanks to the reflective practice. Reflecting on action allows workers to learn from past experience with the goal of performing better in the future (Boud, Keogh and Walker 1985; Schön 1983). In addition, sensing-based interfaces can augment the reflective practice, for example providing sensors for capturing different aspects of experience, user interfaces to facilitate the practitioner in reflecting upon information captured, and infrastructures to share data and reflection outcomes among practitioners. The common denominator is that technology can add realism to exercises, in order to re-create experiences that are as close as possible to real crisis, and allow trainees to experience emotions (e.g. stress) of a similar nature and intensity as the ones experienced under a real emergency (MacKinnon and Bacon 2012). Adding realism to the training experience is recognised to be a key for achieving learning outcomes (Asproth, Öberg and Borglund 2013).

In the remaining of this thesis, theoretical frameworks presented in the next chapter describe how to promote reflection by identifying relevant *cycles* of learning activities. Chapter 4 describes how those activities can be augmented by sensing-based technologies.

3 Theoretical underpinning: Computer Supported Reflective Learning

In order to guide the design of technology to support reflective learning in crisis training, I adopted the Computer Supported Reflective Learning model (hereafter CSRL model) developed by the MIRROR project. The model identifies the requirements to design technology to support reflective learning (Krogstie, Prilla and Pammer 2013). The CSRL model has worked as theoretical underpinning for the development of sensing-based technologies presented in this PhD work, providing a language for guiding the understanding of reflection and drafting requirements for the technology.

After a brief introduction about theories in the field of reflective learning, I describe the CSRL model and how it can be applied to the development of technology. In the following I will use the terms *reflective learning* and *reflection* as synonyms.

3.1 The reflective practice

Boud (1985) defines reflective learning as "a generic term for those intellectual and affective activities in which individuals [. . .] explore their experiences in order to lead to new understandings and appreciations", it is both an individual and collective mental process that turns past experiences into new knowledge. This is also in line with the work of Schön (1983) who further distinguishes between *reflection-in-action* and *reflection-on-action*.

Reflection consists of a three-steps process during which the learner re-evaluates her experiences inspecting behaviours, ideas and feelings; eventually deriving conclusions and lessons learned to that guide future behaviour (Figure 3.1). The process can be iterated multiple times and might influence the learner's behaviour only in the long term.

A key aspect in making a reflective process to happen is the presence of triggers. Triggers are unexpected situations, for example disturbances and perception of uncertainty; but also positive situations like a surprising success. In general, reflection seems to be triggered by awareness of the discrepancy between expectations and the current experience. Reflection might be triggered by an external event

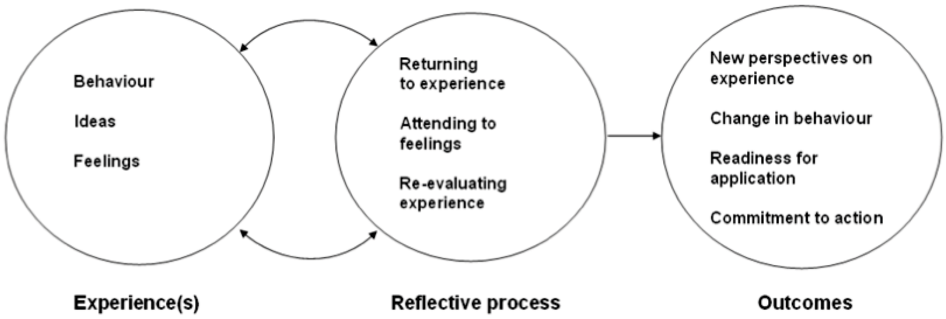

Figure 3.1: The reflection process according with Boud. Figure adapted from (Boud, Keogh and Walker 1985)

or agent (external trigger/accident) or might develop from one's own thinking of a whole series of occurrences over time (internal trigger). Reflection can occur incidentally or intentionally, but in both cases it is a conscious evaluation of an experience. Furthermore people can learn not only from their own experiences, but also from other's experiences directly or indirectly (for example by observing and reflecting on other's actions).

Similar to the work of Boud, Kolb describes experiential learning as a cyclic process named "The Kolb Cycle" (Figure 3.2).

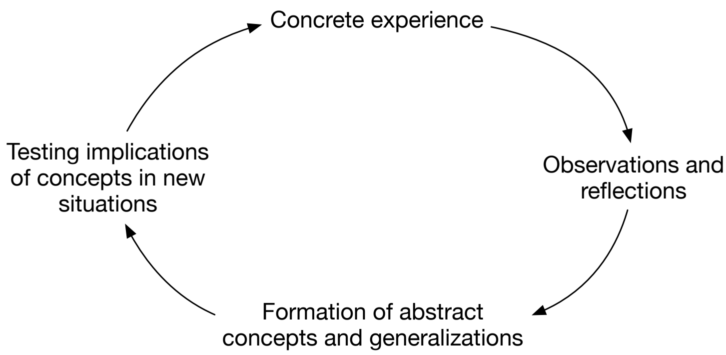

Figure 3.2: "The Kolb cycle", a model of experiential learning. Figure adapted from (Kolb, Rubin and McIntyre 1984)

According with Kolb (1984) reflection is a process that involves not only reinterpreting existing experiences, but also initial perception and interpretation of the raw experience.

For a description of other existing theories in reflective learning see (Daudelin 1996).

Figure 3.3: A debriefing after a physical simulation of crisis management work observed by the author

3.1.1 Collaborative reflection during debriefings

An example of collaborative reflection in crisis management is *debriefing*. As outlined by Boud et al. (1985) debriefing is a form of collaborative reflection because during debriefings a re-evaluation of experience takes place, with explicit attention to emotions, ideas and behaviour.

Debriefing involves "reviewing a difficult episode from a constructive point of view . . . the goal is to extract fundamental lessons learned from the way the event was handled" (Lagadec 1997). It is a collaborative activity involving multiple roles and it is usually performed after a (real or simulated) crisis work experience.

Figure 3.3 shows one of the debriefing observed during the user studies reported in Chapter 5. After a 3-day physical simulation of crisis management operations, the chief manager discusses with team leaders and field workers what went wrong and how to avoid the same issues in the future. Technology is used to visualise the location of operations on a digital map. Data were previously manually entered during the training event.

The outcome which debriefing seeks to obtain is lesson drawing. Previous work experience provides a good source of lesson-drawing which may potentially affect managing, planning and training for future crises. Yet lessons-drawing is often one of the most neglected aspects of crisis management (Lagadec 1997; Stern

1997). The introduction of debriefing into crisis organisations often meets resistance (Lagadec 1997). This might be due to lack of commitment, costs, but also the lack of technologies to make the debriefing more effective.

3.2 Computer Supported Reflective Learning (CSRL), a model

Building on the presented theories and on empirical studies, the MIRROR project has iteratively developed a model for Computer Supported Reflective Learning (CSRL model). The model has been designed to identify requirement, design and implement technology to support for reflective learning (Krogstie, Prilla and Pammer 2013). Rather than providing formal guidelines or pre-defined processes, the model helps to understand and analyse reflection in the workplace and it suggests how technology can support reflective practice.

Following the work of Boud et al. (1985) the model considers reflective learning as “the conscious re-evaluation of experience for the purposes of guiding future behaviour [. . .] as reflection transforms experience from work into knowledge applicable to the challenges of daily work” (Krogstie, Prilla and Pammer 2013). The model specifically addresses reflection in the workplace with *work* and *reflection on-action* as loosely coupled activities that have an impact on personal, collaborative and organisational growth. Therefore the model is well suited to address reflection in the crisis domain in which unexpected adverse events do not allow to schedule clear boundaries between the time to be dedicated to work and to learning.

According with the model, a *reflection session* is a time-limited practice in which reflection happens. Reflection is driven by learning objectives that might be only partially explicated, leaving rooms for open-ended outcomes. Such outcomes may include a change in behaviour, new perspectives and commitment for action (Boud, Keogh and Walker 1985). *Participants* of the session might be a single person (individual reflection) or multiple persons (collaborative reflection).

The model explains reflective learning as a cycle involving four stages of reflection: (i) do work; (ii) initiate reflection session; (iii) conduct reflection session; and (iv) apply reflection outcomes. For each stage the framework specifies relevant sub-steps: specific reflection-useful activities that can be augmented with technology. For example, initiate reflection session includes *decide to reflect* and *frame the reflection session.*

Figure 3.4 depicts the models in terms of *stages*, *inputs* and *triggers*. A *stage* includes sub-activities that can be supported with technology, *inputs* are either raw or more or less contextualised data being exchanged among stages; *triggers* are either external events or internal mental processes that initiate a reflection session. Reflection can be triggered during work, while a change is about to be applied, or during the reflection session itself. In general, reflection seems to be triggered by awareness of discrepancy between expectations and the current experience.

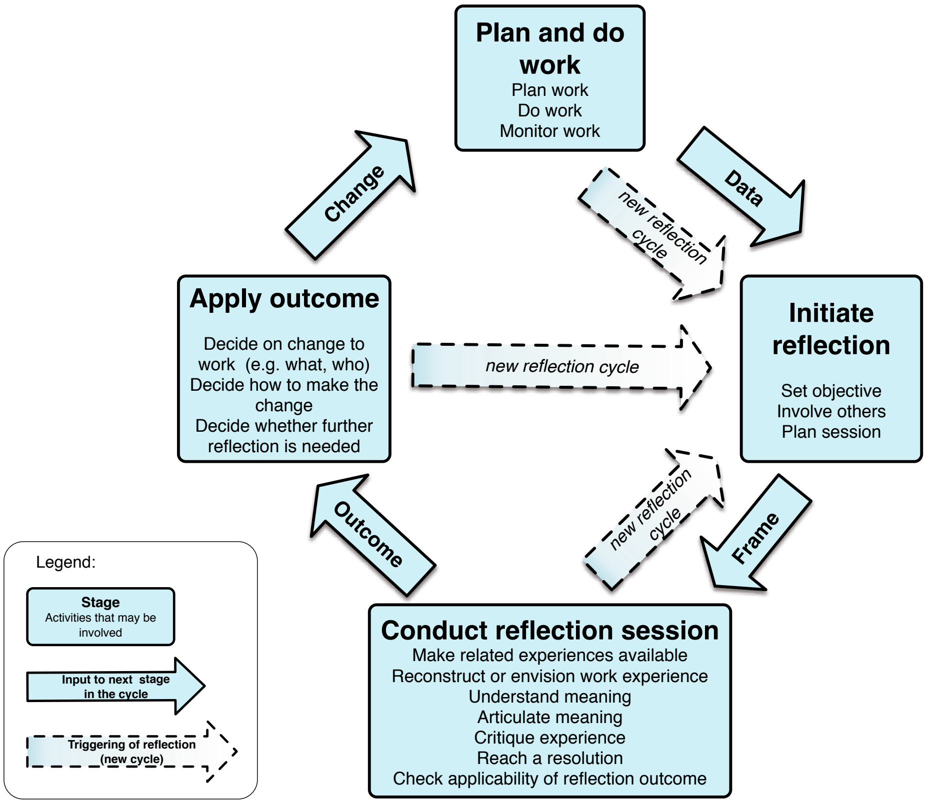

Figure 3.4: CSRL reflection cycle. Figure adapted from (Krogstie, Prilla and Pammer 2013)

Triggers also allow for including more actors in the reflection process, iteratively starting a new cycle based on the results of previous ones. For instance, the outcome of a personal consideration (e.g. how a crisis procedure is applied) might be brought in a team meeting to trigger collaborative reflection, ultimately leading to a change in protocols. In this way, we can look at reflection as a storyline that might involve different actors within the organisation (Prilla, Pammer and Krogstie 2013).

3.3 CSRL applied to crisis training

The CSRL model can be used by designers to choose which technology to use to support reflection activities or do derive requirements for the design of new technologies. For each stage, the CSRL model identifies support that can be provided through technology. For example in the *do work* phase, technology could be used to monitor work and collect data that can be useful for reflection, in *initiate*

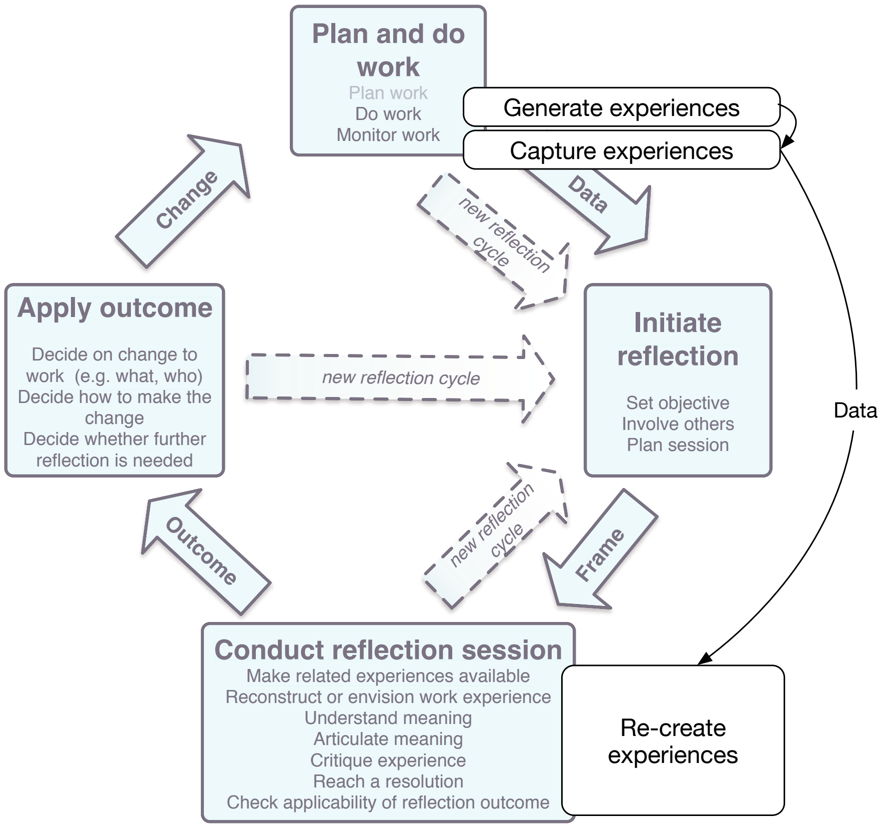

Figure 3.5: Instantiation of the CSRL model to support crisis training

reflection to set the objectives for reflection or to involve others in the session, in *conduct reflection* to share work experience with colleagues; and in *apply reflection outcomes* to decide how the change to work will be implemented.

The model has driven the development of several software and hardware applications within the MIRROR project; to address reflective learning in the fields of social care, health care, business and emergency aid. For a description of the applications see (Schwantzer 2014).

In the case of crisis training I identified that the mapping between the activities described by the CSRL model and technology can be placed in three macro-areas (Figure 3.5):

- technology to **capture** work experiences (for example by means of automatic sensors, a personal diary application, or a timeline visualisation)

- technology to **re-create** work experiences, making use of the captured data to trigger and assist a reflection session with relevant information (for example by allowing to re-evaluate a past experience from multiple point of views, in a context that helps making sense processes during debriefing)
- technology to **generate** new, realistic work experiences for training purposes (for example via virtual worlds, serious games, or tabletop exercises)

The three areas have the common need for innovative interfaces between people and technology. Yet the design of such user interfaces aims at different goals. During *experience capture* the interface should allow the collection of a variety of quantitative data and user-submitted information without interrupting crisis work. The stage of *re-creating* experiences need tools for data visualisation and manipulation capable to re-create a work experiences in a context that promote reflection. Finally *generating* experiences needs interfaces to bring realism and engagement of real crises into a simulated environment. Notably, the *capture* of experiences is done during the work, which is subject to strict crisis protocols that limit the design space for the technology.

Although specific activities from each of the four stages have been considered, the main focus of this investigation is on supporting with technology the stages of *plan and do work* and *conduct reflection session*, since these stages involve activities observed during field studies.

In the following chapter I will investigate how recent advances in the field of sensing-based interaction can provide theoretical tools from human-computer interaction theory for the design of user interfaces to capture, re-create and generate crisis work experience.

4 Theoretical underpinning: Sensing-based interaction

This chapter reviews theories in Human-Computer Interaction (HCI) to inform the design of computer interfaces to support the *capture*, *re-create* and *generate* crisis training experience.

Field studies conducted by the author during physical simulations of crisis work (a description is available in Chapter 5) have identified requirements for the design of technologies to support the CSRL activities. To support the *capture* stage the design goal emerged is to provide unobtrusive, distraction-free user interfaces to enable and control data collection. During *re-creation* and *generation* stages the objective is to provide situated, highly interactive user experiences using data to promote reflection.

The intrinsic physicality of crisis work was very visible during field studies. When I started to design computer interfaces to support reflection for this very specific target group, it seemed to me advantageous to preserve some extent of *physicality* into their user-experience with technology. After surveying HCI literature for theoretical frameworks to facilitate integrating *physicality* into computer interfaces I focused on the aspects of *embodiment* and *tangibility*. Those are characterising traits of sensing-based interfaces (Benford et al. 2005).

Sensing-based interfaces is rather a broad term referring to user interfaces that rely on sensor technology to make interaction between people and computers more intuitive and effective (Zhai and Bellotti 2005). They allow for post-*WIMP* (Van Dam 1997) interaction paradigms, to design user interfaces not relying on traditional *W*indows, *I*cons, *M*ouse and *P*ointers metaphors. Instead, sensing-based interfaces promote "embodied interaction, tangible manipulation, physical representation of data and embeddedness in the real space" (Hornecker and Buur 2006). According to Rogers and Muller (2006) sensing-based interaction allows the design of systems capable to deliver relevant information at appropriate times, which is critical to trigger and sustain reflection; and enable "hands-free control", which is fundamental for unobtrusively capturing data in action.

Theoretical tools to include *embodiment* and *tangibility* into user interfaces are reviewed in the next sections.

4.1 Tangible and embodied interaction

Embodied interaction, as defined by Dourish (Dourish 2001), is a collection of trends emerged in HCI, relying on the common ground to provide a more natural user interaction with digital information. Embodied interaction makes an enormous shift from previous paradigms. Moving from time to space, it takes the interaction "off the screen" into the real world (Dourish 2001); distributing inputs in space, de-sequentialising interaction and reducing the gap between where the information is created where it is accessed. The interactional media, with its affordances, is the interface: "By treating the body of the device as part of the user interface –an embodied user interface– we can go beyond the manipulation of a GUI (Graphical User Interface) and allow the user to really directly manipulate an integrated physical-virtual device" (Fishkin et al. 2000)

Tangible user interfaces (TUIs) are computer interfaces in which technology is embedded into physical objects and spaces, enabling an *embodied* interaction with digital information. In this picture, unlike GUIs which manipulate virtual elements (e.g. icons) with the aid of keyboard and mouse, TUIs integrate both representation and control of computation into physical artefacts (Krumm 2009). This approach allows system designers to be free to experiment with new type of metaphors, taking advantage of users' physical skills and providing interfaces which exploit people's knowledge with the everyday, non-digital, world (Jacob et al. 2008). Since the ways the manipulation of physical media profoundly differs from the manipulation of the digital (Terrenghi et al. 2007), metaphors adopted for the digital world need to be redesigned to meet physical affordances. The design of TUIs as well as other sensing-based interfaces poses new challenges to designers (Bellotti et al. 2002). Those challenges were also further elaborated by Marquardt and Greenberg (2012). Several terms have been used to characterise systems of tangible interfaces: e.g. *tangibles*, *graspables*, *tokens*, *containers*, *phicons*, *tangible bits*; in the following I will call them *tangibles*.

Tangibles are part of the broad field known as Ubiquitous Computing, widely attributed to the work of Mark Weiser. In his pioneering article on Scientific American (Weiser 1991) he envisioned a close coupling between the digital and the physical, to the extent that the technology "disappears into the fabric of the everyday life".

4.1.1 Theoretical frameworks

Over the years several research initiatives have proposed frameworks either to characterise systems of tangibles, e.g. (Fishkin 2004; Jacob et al. 2008; Hornecker and Buur 2006); or to provide opportunities and guidelines to support the design of new TUIs, e.g. (Benford et al. 2005; Shaer et al. 2004; Rogers and Muller 2006).

In 2000, Ullmer and Ishii (2000) took the first steps investigating the design of tangibles. They defined TUIs as computer interfaces that give physical form to digital information, rethinking the interfaces itself as being composed by some sort of "tangible bits" (Ishii and Ullmer 1997). In order to help understanding and building tangibles, they created a conceptual framework and interaction model called MCRit. MCRit, an abbreviation for Model-Control-Representation (tangible and intangible), adapts the Model-View-Controller (MVC) model of GUI-based interaction to the design of tangibles. Besides MCRit highlights the "seamless integration of control and representation" characteristic of tangibles, it redefines the capability of the interface to provide information as a balance between its physical representation (the object's shape and affordances) and a intangible one (e.g. computer graphics and sounds) (Figure 4.1). For example by augmenting physical objects with video-projections and sounds in order to extend the static representation of an object with an intangible, dynamic one.

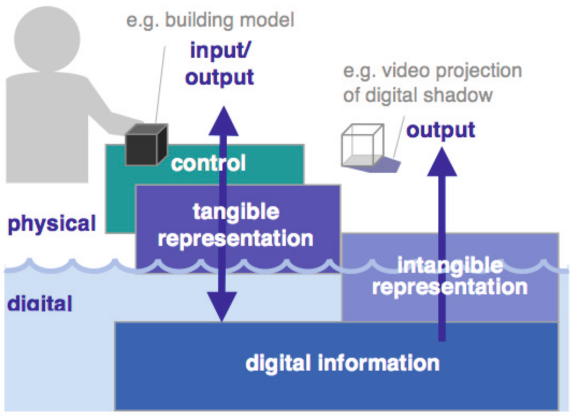

Figure 4.1: Tangible and intangible representations of TUI. Figure adapted from (Ishii 2008)

In fact one of the main pitfalls of TUIs is that while GUIs serve as generic purpose interfaces by allowing multiple kinds of tasks, defined by the software; TUIs serve as special purpose interfaces, each one tailored to a specific set of actions (defined by physical affordances and constrains). A tangible interface can hardly be adapted to work in a context that differs from the one it has been designed for. This trade-off has been defined by Jacob (2008) between Reality and Versatility: it trades the capability of a system of doing many different tasks (like browsing photos, writing a document) with the possibility to accomplish only one single task with a higher level of realism or simplicity.

Following the work of Ullmer and Ishii other research has looked at tangibles from other perspectives. Jacob et al. (2008) identifies four interaction themes with the real world that can be leveraged for the design of TUIs. Hornecker and Buur (2006) present four topics to be considered in scenarios where tangible interaction has social aspects. Fishkin (Fishkin 2004) presents an aggregated perspective on other frameworks, categorising tangible systems as a continuum spectrum according to the level of embodiment and metaphor they provide. Finally Ullmer et al. (Ullmer, Ishii and Jacob 2005) envision TUIs as a systems of *tokens* and *constraints*. The former are discrete physical objects that represent digital information, the latter mechanical or visual confining regions that are mapped to digital operations. By the interaction phases of association and manipulation of tokens within a system of constraints it is possible to map physical actions to a set of computational operations in a grammar of ways. For example the presence or absence of a token in a constrained area could be easily digitalised in binary information to trigger a digital operation. For a literature review on other frameworks see (Mazalek and Van Den Hoven 2009) and (Shaer and Hornecker 2009).

4.1.2 Applications in reflective learning

Although the relation between tangibles and reflection has not been thoroughly investigated, several works have shown that TUIs might be beneficial for learning (Marshall 2007); for a review see (O'Malley and Stanton Fraser 2004). Although these often focus on applications of TUIs for children and classroom environments, TUIs might have possible benefits on learning on a broader scope. Those benefits include the support to more natural (Terrenghi et al. 2005) and situated (Klemmer, Hartmann and Takayama 2006) learning, and increased reflection and engagement (Rogers and Muller 2006) due to the link between physical action and digital feedbacks. Moreover TUIs foster collaboration (Rogers and Rodden 2003), in which they increase visibility of others' actions and allow for concurrent interaction.

Theoretical tools adapted from the presented frameworks have driven the design of sensing-based interfaces described in Chapter 6.

In the next chapter I will present the research methodology adopted throughout the work, providing details on the field studies performed and prototypes built.

5 Research methodology

The aim of this chapter is to present the research methods and tools adopted. Although not all of these methods have been explicitly reported in the papers, they have been important to understand the users and the domain.

5.1 Research overview

The work in this thesis is based on design science research (Hevner and Chatterjee 2010; March and Smith 1995). Design science provides theoretical tools to study and understand a specific domain, as well as processes to build artefacts with the aim at improving an environment (Simon 1996). The work unfolded by interweaving field studies to understand the crisis domain, and turn opportunities observed into system requirements; with design iterations to build technologies to address those opportunities.

The design science approach meets the aim of this research work, which lies in the design of technologies for better crisis training (RQ1-RQ2). The focus of design science on rapid iterations between the construction of artefacts and their evaluation (Hevner and Chatterjee 2010) also makes a good strategy for the investigation of RQ3.

Hevner et al. (2004) describes design research as a sequence of three tightly coupled cycles of activities (Figure 5.1). Each of the three cycles must be present and visible in a design science research project (Hevner and Chatterjee 2010).

- The *relevance cycle* involves designing and running field studies with exploratory or evaluation purposes. While the former type derives requirements for technology to be implemented in prototypes, the latter type cycles between defining acceptance criteria and introducing technologies into the environment for field testing, aiming at improving artefacts until research goals are met.
- The *rigor cycle* includes both a continuous process of keeping design work informed by relevant grounding theories, and a retrospective effort in validation and extension of those theories. This cycle qualifies the research to maintain an innovation approach able to bring research contributions.

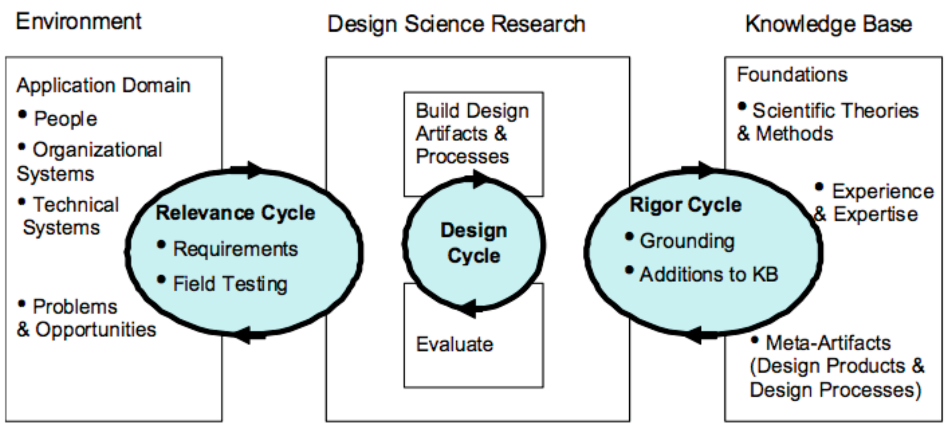

Figure 5.1: The design cycles, figure adapted from (Hevner 2007)

- The *design cycle* rapidly iterates between the production of a prototype and its formative evaluation to gather feedback and refine the design. This stage is fed with requirements from the relevance cycle and theories from the rigor cycle; it returns artefacts for field test to the former and theoretical knowledge to the latter.

To implement the main research strategy, several methods have been adopted. I used a mix of qualitative research methods to account for the unpredictability in an in situ study (Rogers et al. 2007). Observations, interviews and researchers' notes were the primary means to collect data on the field. Scenarios and personas drove the design phase. Open source hardware and software toolkits were largely adopted to turn mockups into working prototypes. Finally questionnaires and interviews were used during prototypes formative evaluations and field tests.

The choice of these methods required to have access to people, knowledge and protocols of organisations working in the crisis domain. This research strategy was facilitated by having crisis training organisations, as members of the MIRROR consortium. Moreover, throughout the duration of the work, discussions with members of the consortium and co-authored publications helped in shaping research strategies and partially influenced the work.

5.2 Research activities

This section details the activities performed and how methods have been instantiated. A chronological account of the research process is provided in Figure 5.2.

During the progress of the research, several activities concurrently unfolded intra and inter the *relevance*, *design* and *rigor* cycles.

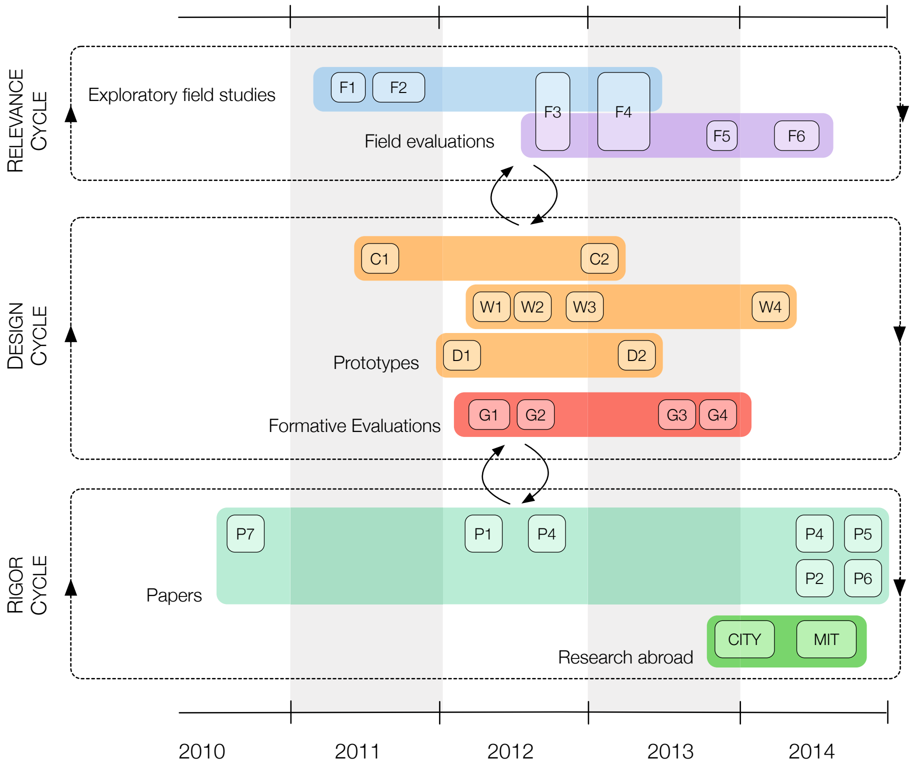

Figure 5.2: Timeline of research activities

The work started off with two exploratory field studies aimed at understanding the crisis training domain, its needs and challenges. Soon enough early design ideas were turned into low-to-high fidelity prototypes in short iterations.

In the central course of research, activities iterated between new prototype releases and consequent formative evaluations; often recurring to new field studies to keep the design process updated with new requirements. Prototypes presented in focus groups with workers facilitated discussions, triggering a better understanding of the domain, which in turn led to new ideas. Furthermore, prototypes facilitated the reminiscence of work experience, bringing new perspectives into the study.

In the final iterations of the work, working prototypes acted as means to validate and extend theories as part of the *rigor cycle*. Results from evaluations provided insights to validate and extend theories of reflective learning, as reported in P6.

Research outcomes were reported in academic publications (Chapter 6) and research contributions (Chapter 7) emerged. Finally the work focused on exploring generalisation during research abroad (Appendix B) and on investigating commercial exploitation of research contributions (Section 1.4.3).

Throughout the process literature in reflective learning (Chapter 3) and sensing-based interaction (Chapter 4) informed the design work. While the former identified *what* activities and processes to trigger reflection can be enhanced with technology; the latter provided guidelines on *how* to design technology artefacts.

In the following sections, a description of field studies performed and methods adopted are provided in Section 5.2.1. The production and formative evaluation of prototypes is covered in Section 5.2.2.

5.2.1 Field studies

The primary investigation method selected to understand the crisis domain and evaluate artefacts produced by the design cycle has been *field studies* (Robson 1993). In this work, field studies had a twofold objective. Some studies acted as exploratory research to inform the design of technology, some others as field evaluation for the tools developed; some else covered both aims.

An overview of the field studies performed between years 2011-2014, in relation with research questions and papers, is presented in Table 5.1

Table 5.1: List of field studies performed

		Aim			Methods			
ID	Date, duration	Exploratory	Evaluation	Participants	Observations	Interviews	Questionnaires	Papers
F1	Mar. 2011, 2 days	•		several teams	•	•		P1
F2	Oct. 2011, 3 days	•		several teams, 1 manager	•	•		P1, P3
F3	Oct. 2012, 2 days	•	•	5 field workers, 1 manager	•	•		P1, P3
F4	Apr. 2013, 3 days	•	•	4 field workers, 1 manager	•	•	•	P1, P3, P2
F5*	Dec. 2013, 30 days		•	8 field workers			•	P2, P3, P6
F6	Apr. 2014, 2 days		•	27 field workers, 1 manager	•		•	P2, P3, P6

*The author was not present during the study

The setting for the majority of the studies was medium to large-scale physical simulation of crisis work (drills). The first exploratory study (F1 in Table 5.2.1) took place during attendance at a real crisis management event. A description of a typical physical simulation was provided in Chapter 2. Objectives of those simulations were to train workers against protocols, rescue procedures, and test of equipment. Notably, the observed events also offered opportunities for team building and sharing of experiences, as part of official and unofficial social gatherings.

The observed training events, involved personnel from a range of crisis management organisations operating in northern Italy, coordinated by *ANPAS-Piemonte*[1] and *SEIRS*[2] organisations. Contacts with these institutions have been initiated via a partner of the MIRROR consortium. A wide range of roles were observed, including field workers (firefighters, paramedics, police agents), team coordinators, disaster manager, technical and radio staff. The number of participants in our studies varied between dozens of workers observed in the exploratory studies to smaller groups who where actively involved during interviews and prototype evaluations.

Observations, researcher notes and interviews were the primary means to collect data. In addition questionnaires were employed during evaluation studies.

Workers were shadowed while performing rescue work. To this respect, my role as observer strived to be, as defined by Walsham (2006), *neutral*; meaning that people being shadowed should not perceive the researcher as biased by previous views on people, processes or organisations. Video recording, performed with both handheld and head-mounted cameras worn by simulations' participants, provided multiple point of views on the observed events. Qualitative data collection methods were supplemented by descriptions of protocols, procedures and best practices provided by the organisations involved in the studies. Data captured were handled in observance of NTNU and MIRROR policies. No compensation was given to the workers after participation to the studies.

Data collected from researchers' notes, interviews and questionnaires, together with video recording and logs were analysed with qualitative research methods (Robson 1993). The focus of the analysis was twofold.

During exploratory studies the focus of attention was on how practitioners capture aspects of their work experiences. It allowed to identify on one hand what information is relevant for reflection; on the other hand what technology to capture information is already in use or is desired. The outcome of this phase produced a set of requirements to drive the design of technology; including challenges, system requirements, scenarios and personas. This result fed the *design cycles*, for the construction of prototypes.

During evaluation studies the focus was on measuring how well prototypes perform against user acceptance, usability of the systems, and impact on learning. Selected workers were provided with prototypes for test during field work. Workers were walked through the use of technology by a researcher and a set of tasks to be accomplished was given to each participant. Participants' interactions with the technology were observed and video recorded with wearable cameras; in addition prototypes were configured to log modes of operation.

[1]ANPAS-Piemonte crisis management organisation - http://anpas.piemonte.it
[2]SEIRS crisis management organisation - http://seirs.org

After each test, researchers followed up with observations, interviews and questionnaires. Questionnaires offered a high-level quantification of feedback, while observations and interviews aimed to ground this feedback in the context of usage. Questionnaires in use during the evaluations were adapted from the MIRROR evaluation toolbox (Knipfer, Wessel and DeLeeuw 2012), which provides surveys to measure user acceptance, perceived learning success, and the intention to change behaviour. These questionnaires are a generic instrument that build on the Kirkpatrick framework (Kirkpatrick and Kirkpatrick 2009).

5.2.2 Design iterations

Design and prototyping work was driven by requirements, scenarios and personas generated during field studies. The design process followed a *user centred approach* (Maguire 2001; Gulliksen et al. 2003).

A total of eight prototype iterations were completed. Table 5.2 overviews the prototypes developed, tools and technologies used during development in relation with the papers that described the work. Prototypes included a mobile app (*CroMAR*, two iterations), wearable sensors (*WATCHiT*, four iterations) and a technology-augmented board game (*Don't Panic*, two iterations).

Building each prototype involved a mix of software, hardware and material development. Software was written for a variety of systems. The development of hardware included design, production and test of electronic circuits. In some prototypes the circuits developed were embedded in hard-shells that were custom-designed and produced in plastic or wood (material development). The design of the appearance for the resulting software/hardware hybrid artefact aimed either at protecting electronic circuits during field test or to provide specific affordances for interaction.

During development I largely adopted rapid prototyping techniques in order to keep design iterations short and produce incremental improvements based on frequent feedbacks exchange with end users. To this end a wide range of open source toolkit were used, including Arduino[3] and RaspberryPi[4] hardware development platforms. Digital manufacturing techniques were largely adopted, including CAD software, 3D printing and laser-cut production. These activities were essential to the development of knowledge to the investigation of RQ3.

After each prototype was built, a formative evaluation followed. User testing allowed for maintaining a user-centred design perspective, to introduce new ideas into the process, and to test prototypes in a controlled setting before releasing them for field testing.

To this intent, focus groups with crisis workers were performed. A list of focus groups performed, and prototypes tested is depicted in Table 5.3. Focus groups with workers were essential for fuelling the design activity. Moreover, meetings often saw the participation of the same workers who were previously shadowed

[3] Arduino platform - http://arduino.cc
[4] RaspberryPi platform - http://raspberrypi.org

Table 5.2: List of prototypes built

ID Ver.	Name	Released	Prototyping tools	Development: Software	Development: Hardware	Development: Material	Papers
C1	CroMAR	Jul-11	iOS,	•			P1,P2
C2		Jul-12	Augmented Reality	•			P2
W1	WATCHiT	Jan-12	Arduino, Textiles	•	•		P3
W2		Aug-12	ZigBee, Bluetooth	•	•		P3
W3		Sep-12		•	•		P3
W4		Aug-13		•	•	•	P2, P3
D1	Don't Panic	Mar-13	Paper, wood			•	P4, P5
D2		Aug-13	Sifteo, RapsberryPi Laser cut	•	•	•	P5

Table 5.3: List of focus groups performed

ID	Date	Participants	Prototypes tested
G1	Apr-12	9 field workers	W1, D1
G2	May-12	1 disaster manager	C1, W1
G3	Jul-13	3 field workers, 1 manager	D2
G4	Sept-13	8 IT students, 4 HCI experts	D2

during physical simulations. It was therefore possible to ground discussions into specific episodes previously observed on the field.

Figure 5.3: Participants of the G3 group filling in SUS questionnaires, after the test of D2 prototype

During focus groups low and high fidelity prototypes were evaluated. The typical setting of focus groups performed is represented in Figure 5.3. Low-fidelity prototypes acted as technology probes (Hutchinson et al. 2003). Despite their evident usability issues, they were essential to create new scenarios of use and identify technological and usage challenges. Higher-fidelity prototypes underwent usability tests (Dumas and Fox 2009) using System Usability Scale (SUS) (Jordan et al. 1996, page 189).

In the following chapters the papers that added up to the results of this thesis are presented.

6 Results

In the previous chapter the research background and methodology adopted during the work were presented. This chapter summarises the papers that document the conducted research.

6.1 Overview of research papers

The research work has been published in two journal papers and four conference papers, one paper is currently ready for submission. In this section, papers that present the results of this thesis are summarised. Each summary includes:

- Title
- Authors and roles in the paper
- Abstract of the paper
- Where the paper was published
- A short description of how the paper relates to the research questions

Papers are reprinted in full in Part II of the thesis.

In addition to the papers presented in this section this PhD work has produced seven peer-reviewed papers. These papers present incremental achievements in research and have been summarised in in Appendix A.

6.2 Paper 1

Title: CroMAR: Mobile Augmented Reality for Supporting Reflection on Crowd Management

Authors: Simone Mora, Alessandro Boron and Monica Divitini

Authors' contributions: Mora led the research and the paper writing. He was actively involved in design, development, and evaluation of the system. Boron developed part of the described prototype and contributed to the paper with the description of the technical implementation. Divitini provided general supervision for the research and the paper writing.

Abstract: This paper discusses the usage of Mobile Augmented Reality (MAR) to support reflection on past events, using reflection on crowd management as scenario. Computer based support to reflection generally relies on the visualization of information connected to the experience one is reflecting upon. Different metaphors have been adopted to support easy access to relevant information within the reflection process, e.g., timelines and word clouds. In this context, MAR represents an interesting alternative because it can be used to promote reflection in the specific location of the event by augmenting it with relevant information. In this way, the authors can expect the reflection process to be grounded in a context that helps to make sense of the information and reflect on alternative paths of action. The paper presents the scenario of usage, together with the design, development, and evaluation of the prototype, *CroMAR*. Based on this experience, the authors identify challenges connected to the usage of Mobile Augmented Reality in terms of support for reflection, interaction, and design methodology.

Published in: International Journal of Mobile Human Computer Interaction (IJM-HCI), 2012

Description: This paper initiates the design process of technology to support reflection (RQ2) by investigating the use of *Mobile Augmented Reality* (MAR) to support debriefing after crowd management activities. To date, it is the first time that MAR is used for such purpose. Crowd management is a safety-critical activity performed by crisis workers during large public events (e.g. parades, sport events). It entails regulating flows of people to avoid the overcrowding of public places that might lead to dangerous consequences.

Debriefing, as reported in Chapter 3, is a form of collaborative reflection in which a re-evaluation of experiences takes places. The paper presents *CroMAR*, an iPad app designed by the authors, allows for browsing reflection-useful information. The system focuses on supporting navigation of reflection-useful information along the time and space dimension. Visualisation of information is provided in-situ, in a physical context that helps making sense of the information and reflect on alternative paths of actions. Also, the system provides support in involving others in the reflection process and in sharing of its outcome.

The proposed design has been implemented in a working prototype of an iPad app (Figure 6.1), with focus on modularity and extensibility. The prototype has been evaluated in a focus group with experts (G2 in Table 5.3). The study highlights challenges in supporting reflective learning with MAR tools, with focus on user experience. First the research requires a better understanding of the conditions that makes MAR a better approach compared to other visualisation approaches (e.g. maps, timelines). Second, it claims the need for providing scaffolding mechanisms to the reflection process; to make sure that relevant information for a given session is explored. Acknowledged by experts that the physical exploration of space provide scaffolding for exploration of information, it is necessary to study when it actually promotes reflection.

Figure 6.1: *CroMAR* early prototype

The results from this paper have fed new design iterations for *CroMAR*. The design of new functionalities has followed more closely the guidelines provided by the CSRL model that was being developed at the time. A new prototype of *CroMAR* and its closer mapping to the CSRL model is described in P2.

6.3 Paper 2

Title: Supporting Debriefing with Sensor Data: A Reflective Approach to Crisis Training

Authors: Simone Mora and Monica Divitini

Authors' contributions: Mora led the research and the paper writing. He also led the design of the presented technology and directly implemented or supervised the implementation of the prototypes. Both authors attended the evaluation studies. Divitini provided general supervision for the research and the paper writing.

> *Abstract:* In this paper we present our exploration into the use of sensor data to promote debriefing after training events simulating work experiences. In this way we address one of the core challenges of crisis training, namely the difficulty to exploit the full potential of training events, e.g. during drills. The paper is theoretically grounded in the theory of reflective learning. The theoretical understanding is used for informing

> the design of *WATCHiT*, a wearable device for collecting sensor data during an event, and two applications for promoting debriefing in two different scenarios, *CroMAR* and Procedure *Trainer*. *CroMAR* supports disaster managers during in-situ debriefing after large events, while Procedure *Trainer* supports a team in reflecting after the simulation of a medical emergency procedure. The evaluation of the two applications shows that sensor data can be successfully used to support debriefing in both scenarios. Based on our experience, we draw lessons learned for the design of systems supporting debriefing in training events.

Published in: Proceedings of Information Systems for Crisis Response and Management in Mediterranean Countries (ISCRAM-MED), 2014

Description: This paper investigates how technology can improve the efficacy of debriefing with tools to capture data from work experiences (RQ1) and with user interfaces to browse information designed to facilitate triggering and supporting reflection activities (RQ2).

In this perspective, the paper presents an ecology of three technology tools to assist a wide range of scenarios. Also, in this work technology mapping with the CSRL model (Chapter 3) is made explicit. Two applications: *CroMAR* and *WATCHiT* also described in P1 and P3 and are presented in the last stage of their evolution. *Trainer*, introduced in this paper, is a smartphone application to support a quick reflection session on the implementation of protocols (e.g. medical procedures) that can be done by the worker alone or in team. Building on results from tools evaluation during physical simulations, the paper presents lessons learnt about the design of systems to use of sensor data for supporting debriefing.

First it is acknowledged that sensor data has to be complemented by qualitative information in order to set the right focus for reflection and avoid over-sighting qualitative, yet critical aspects of the work that cannot be captured with quantitative methods.

Second it suggests the use of *visualisation* and *storytelling* as mechanisms to promote sense-making processes for turning data into useful learning contents. Visualisation helps understanding the data by *re-creating* a context that help spotting discrepancies with other sources and, in turn, triggers reflection. Storytelling happens when a visualisation need to be interpreted and explained both to oneself and to others, connecting data to the human memory of the event. Also, how to motivate the user in capturing data needed for visualisation and storytelling is an open challenge.

Third, the proposed technologies aim at bringing debriefings out of the traditional office setting but not as substitutes, rather to complement the current practices by creating smooth transitions among different debriefing (and thus reflection) cycles. These propositions will guide future research to leverage sensor data in debriefings.

6.4 Paper 3

Title: WATCHiT: a modular and wearable tool for data collection in crisis management and training

Authors: Simone Mora and Monica Divitini

Authors' contributions: Mora led the research and the paper writing. He also presented the paper at the conference. Mora directly implemented or supervised the implementation of the prototypes. He also conducted the field studies and evaluations. Divitini provided general supervision for the research and the paper writing.

Published in: Proceedings of the European Conference in Ambient Intelligence (AMI), 2014

Abstract: We present *WATCHiT*, a prototype of sensor augmented wristband computer for data collection during crisis response work. During crises, information about the environment (e.g. to map the territory) and the rescuers (e.g. for assessment of workers' condition) offers help to support coordination of work, post-emergency debriefing and to build realistic training scenarios. Being each crisis nearly unique it is important to collect data from every single occurrence, yet it is difficult to foresee the type of data and context information that is relevant to capture. *WATCHiT* features: (1) wearable sensors, (2) easy customisation of the type of information sensed, including both quantitative and qualitative data; (3) an intuitive, distraction-free user interface for controlling the data capturing procedure. Our design process has been driven by user studies during training events characterised by a high degree of realism; our prototype has been successfully evaluated with experts against technology acceptance.

Description: This paper presents the design research that led the development of *WATCHiT*, a wearable computer for data collection in-action during crisis response work (Figure 6.2). The design of *WATCHiT* has been the primary mean of investigation for experience-capturing tools (RQ1). Field studies conducted by the authors (detailed in Chapter 5) have produced seven challenges for the design of technology tools to support data collection during real or simulated crisis. The drafted challenges highlight *what* data are relevant to be captured and *how* to collect them. Data captured can be used to feed reflection during debriefings (as shown in P2) as well as for helping coordination on the field and support decision-making processes.

The challenges drove the design of *WATCHiT* by establishing three core requirements for the technology. *WATCHiT* must be implemented to be *wearable* -to achieve the highest degree of mobility in sensing-, *modular* -to allow customisation of the type of data captured to specific crisis scenarios-; finally it has to feature a *distraction-free user interface* to disrupt as little as possible the work. The requirements were gradually implemented in three prototyping iterations (Figure 6.2). Prototypes were built with the aid of rapid prototyping tools and techniques, in accordance with the investigation of RQ3. Each prototype featured a mix of software and hardware technologies, and an increased degree of wearability. Modularity is implemented as an architectural choice with physical sensor modules that allow for transient customisation of sensing capabilities of the device.

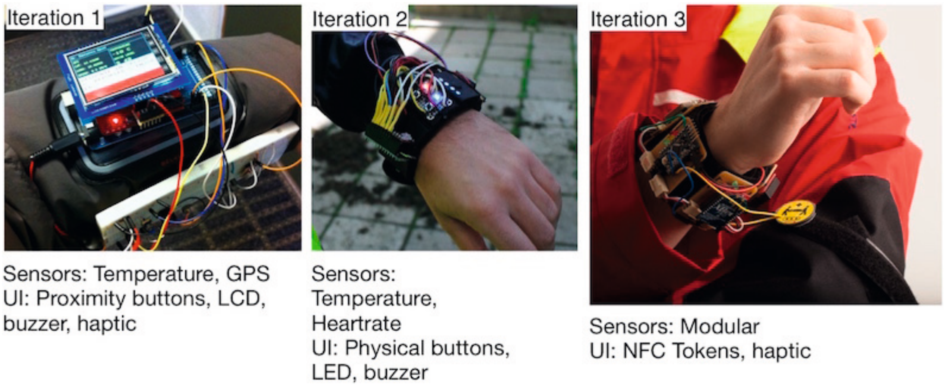

Figure 6.2: Three prototyping iterations for *WATCHiT*

The requirement for distraction-free user interfaces has been implemented with the design of a novel sensing-based interface grounded on previous works on mnemonic body shortcuts and body-centric interaction (Guerreiro, Gamboa and Jorge 2008; Chen et al. 2012). In this work body shortcuts are specialised to assist data capturing processes. Areas on work uniforms and tools (identified by RFID tags) trigger digital operation when the worker puts *WATCHiT* on. Each shortcut can be pre-configured to control the activation of specific sensors and to tag the data that is being captured with contextual information. User evaluations performed during physical simulations of crisis work have shown that the interaction technique is well accepted and *WATCHiT* is suitable to be used during simulated crisis work.

WATCHiT has been used to capture experiential data in order to feed technology-assisted debriefings thanks to the integration with *CroMAR* and *Trainer*, as described in P2. A new prototype and summative evaluation for the tool are described in P6.

6.5 Paper 4

Title: Don't Panic: Enhancing Soft Skills for Civil Protection Workers

Authors: Ines Di Loreto, Simone Mora and Monica Divitini

Authors' contributions: All the co-authors contributed to the research. Di Loreto, first author, led the game design and coordinated the paper writing. Mora contributed to game design with his knowledge of crisis training. He also contributed to the documentation of the work in the paper. Divitini provided general supervision for the research and the paper writing.

Published in: Proceedings of the International Conference on Serious Games Development Applications (SGDA), 2012

Abstract: Don't Panic is a serious game created to enhance soft skills in the crisis management field. The game is conceived to (i) add the fun element to training about stressful situations linked to panic management and (ii) teach skills such as communication styles, team management and coordination, time management, stress management and coping strategies. In this paper we present the first paper-based version of the game and its evaluation. The paper discusses the game design motivations, the methodological reasons behind its conception, and presents a pilot study. Results show that, even in its paper version, the game is a promising tool if linked with adequate and realistic procedures. This opens methodological questions about the role of computer based serious games.

Description: This paper contributes to the design of novel sensing-based interfaces for supporting reflection (RQ2) by studying how serious games can be used as a tool to deliver realistic crisis work experiences. Serious games can complement other forms of training (for a list see Chapter 2) by enhancing workers' communication abilities, stress management and coping skills. The fun element typical of (computer or traditional) games can act as a motivation factor to engage workers in training. Furthermore games based on sensing-based interfaces can exploit tangible and embodied interaction to foster collaboration maintaining a link with the physical nature of crisis work.

After presenting the state of the art of serious games for crisis training, the paper dives into the description of *Don't Panic*, a board game designed by the authors. The game aims at training soft skills in the management of situations where diffusion of panic might put the population at risk. During a game session different potential panicking events take place in the city represented on the board. The players have a limited time to calm down the situation, before the panic spreads and they lose the game. The game aims at teaching communication styles useful to manage crisis events but also foster team building.

The paper details game mechanics and rules. A paper prototype of *Don't Panic* (Figure 6.3) is presented and evaluated in a pilot study with 10 crisis workers who played the game. The mockup, featuring no technology support, was used to validate game mechanics before moving proceeding to the design of a technology-augmented version of the game that is described in P5. The addition of technology can release the players from doing game management tasks which disrupted the game experience in the paper mockup. Moreover technology can be used to to add computer interactivity, for example by means of audio and graphic feedbacks.

Figure 6.3: Paper mockup of “Dont’ Panic”

6.6 Paper 5

Title: The interactive-token approach to board games

Authors: Simone Mora, Ines Di Loreto and Monica Divitini

Authors’ contributions: Mora led the design and implementation work. He was also the main contributor of the paper. Di Loreto designed the board game that is used as example in the paper. Di Loreto and Mora jointly designed and attended evaluation studies. Divitini provided general supervision for the research and the paper writing.

Published in: Ready for submission

Abstract: Recent advances in interactive surfaces and Tangible User Interfaces have created a new interest in digital board games, aiming at mixing the benefits of traditional board games with the interactivity of video games. Within this strand of research we propose a new approach centred on the concepts of tokens, constraints, spatial expressions and interaction events. While mainstream solutions implement game interaction using interactive surfaces, our approach relies on physical manipulation of interactive objects on conventional surfaces. We illustrate the proposed approach by describing the design and development of a game for training of emergency workers. Building on feedbacks from

user evaluation and our experience with the development, we outline design opportunities and challenges of the approach.

Description: This paper presents a novel approach to the digitalisation of board games. As detailed in P4, board game dynamics can be adopted to generate realistic work experiences for training purposes. The approach presented in the paper can be used to drive the design of digital board games based on sensing-based interfaces. The design aims at enhancing interactivity and realism of the generated experiences, eventually pointing at triggering and supporting reflection (RQ2).

Rather than implementing games for interactive surfaces (e.g. touch-screens) the presented approach relies on the physical manipulation of interactive objects on conventional surfaces. After reviewing state of the art technology for digital board games, the approach is presented and grounded in existing frameworks of tangible user interfaces. To facilitate implementation of the approach into the design practice of digital board games a three-steps process is presented.

The approach and process presented in this paper have been used to drive a new design iteration for the game introduced in P4., pointing out the role of technology as facilitator for generating engaging game experience and for supporting post-game reflection and mapping with the real work.

In the new, technology-augmented prototype (Figure 6.4), social affordances of traditional board games, in terms of prompts for cooperation and discussion, are preserved. This is functional to the serious role of *Don't Panic* as facilitator for storytelling and team building. At the same time the added computer interactivity provides a game experience which is more immersive and less disrupting compared to the paper mockup presented in P4. This allows for generating, by means of the game, a simulated work experience (management of panicking crowds) that re-create as much as possible conditions of emotional stress and decision making under time constraints, typical of real work.

The paper also describes the technical challenges faced by the authors during the prototyping process, providing input to the study of RQ3. A mix of software, hardware, laser-cut and 3D printing techniques has been orchestrated in order to fully implement game dynamics and produce a prototype of a game that can be played for an entire session without major disruptions. Beside driving a new design iteration of *Don't Panic* the approach proposed in the paper can inspire the design of digital board games for other domains.

6.7 Paper 6

Title: Context Becomes Content: Sensor Data for Computer Supported Reflective Learning

Authors: Lars Müller, Monica Divitini, Simone Mora, Verónica Rivera-Pelayo and Wilhelm Stork

Figure 6.4: Technology-augmented "Don't Panic" working prototype

Authors' contributions: Müller led the writing of the paper and contributed with one of the case studies. Mora designed the systems presented in the second case study. Mora also designed and conducted the evaluation of the system. Rivera-Pelayo contributed with state of the art about the quantified self and to the methodological part. All the authors contributed to draw lessons learned and theoretical implications from the two studies. Divitini and Stork contributed with supervision during the writing process.

Published in: IEEE Transactions on Learning Technologies

Abstract: Wearable devices and ambient sensors can monitor a growing number of aspects of daily life and work. We propose to use this context data as content for learning applications in workplace settings to enable employees to reflect on experiences from their work. Learning by reflection is essential for today's dynamic work environments, as employees have to adapt their behaviour according to their experiences. Building on research on computer-supported reflective learning as well as

> persuasive technology, and inspired by the Quantified Self community, we present an approach to the design of tools supporting reflective learning at work by turning context information collected through sensors into learning content. The proposed approach has been implemented and evaluated with care staff in a care home and voluntary crisis workers. In both domains, tailored wearable sensors were designed and evaluated. The evaluations show that participants learned by reflecting on their work experiences based on their recorded context. The results highlight the potential of sensors to support learning from context data itself and outline lessons learned for the design of sensor-based capturing methods for reflective learning.

Description: This paper proposes the use of context data as content to support reflective learning in workplace settings. Three design decisions have to be made to turn context into content: *what context* is relevant to be captured, *how to capture* it and *how to visualise* it to support reflection. While the elaboration of the first two decisions add to RQ1 by providing guidelines for the design of tools for experience collection, the third decision provides insights to RQ2 by guiding the design of interfaces that use data visualisation methods to sustain reflection. The first two decisions were already explored drafting design challenges for data capturing tools (P3). In this paper they are further elaborated.

Compared to P3 the paper adds that the decision of *what context* is made harder by the unpredictability of outcomes typical of the reflective practice, and by the need for interpretation required by the unstructured nature of context data. Further, the paper groups context data in three categories: *task*, *affective* and *social*. *Task context* relates directly to the work process and is therefore easy to understand. *Affective context* might work as a marker to recognise relevant episodes for reflection; because if something happens during the day, it will trigger an emotional reaction that can be captured with sensors. Finally *social context* is important for many collaborative work practices since the interactions with other people (colleague, customers, patients) constitute an important aspect of many experiences to reflect upon. *How to capture context* is also further elaborated in this paper. Three methods are proposed. Data can be *self-reported* by the users, thus providing a subjective impression on an experience (e.g. by means of digital diaries). Data can be *self-reported from third parties*, in this way an external perspective is made available to the reflecting person. Finally data can be captured *automatically* by sensors and applications; for example by means of stress or activity-tracking sensors. Finally, the paper introduces a third design challenge connected to *visualisation of context*. In order to be effective in triggering and sustaining a reflection sessions, data should be visualised from multiple perspectives. The social (comparing data over multiple users), spatial (the location data were captured) and historical perspectives (evolution of data samples over time) are considered as effective for reflection.

These design dimensions are functional to build technology tools that implement the stages of the CSRL cycle (Chapter 3). While what context and how to capture it pertains designing of technology to support the *plan and do work* stage of the model, *how to visualise data* provides support for the subsequent stages of *initiate reflection* and *conduct reflection session*. Methods borrowed from persuasive technology and quantified self are presented to motivate the user in the data collection process

To evaluate the proposed approach the paper presents two case studies. The first case builds on the use of *WATCHiT* (P3) and *Trainer* (P2) to support reflection after crisis work. The second case is an application to support reflection for dementia carers designed by the the paper's co-authors. Field evaluations show that participants were able to learn from the visualised context. Capturing tools should be therefore be easy to adapt, in order to allow the users to deal with the unpredictability of relevance of the captured context. This challenge has been addressed in *WATCHiT* (P3) by means of physical sensor modules.

6.8 Paper 7

Title: A Unified Architecture for Supporting Direct Tag-Based and Indirect Network-Based Resource Discovery

Authors: Simone Mora and Babak Farshchian

Authors' contribution: Mora conducted the design work and wrote the paper. Farshchian provided feedback throughout both the design and writing processes.

Published in: Proceedings of the European Conference on Ambient Intelligence (AMI), 2010

Abstract: Discovering and integrating ambient computational resources is a central topic in AmI. There are two major existing approaches: indirect network-based resource selection and direct tag-based resource identification. We motivate the need to integrate the two approaches through a scenario. We then present an architecture for a pluggable discovery system called UbiDisco. We demonstrate how UbiDisco implements a seamless integration of the two approaches at user interaction level through a framework for implementing discovery actions.

Description: This work brings useful insights for the rapid prototyping approach adopted in this PhD (RQ3). As demonstrated in P2 and P6 the CSRL cycle is supported by a set of diverse technologies spanning from wearable and physical computers to apps for tablets and smartphones. Enabling workers to easily link those tools in order to allow data exchange is critical to build custom, scenario-specific ecologies of tools to support the different stages of the reflection cycle. Integrating different apps is technically complex since it involves serialisation of data, configuration of wireless networks and interaction of back-end services such as databases. From the perspective of the user it involves filling in configuration details. This activity might be very complex on mobile and wearable tools.

The paper presents a modular approach to software components for service discovery that blends the benefits of direct tag-based and indirect network-based discovery.

The approach has been implemented in a middleware, called *UbiDisco*, that allows for discovery and customisation of computational resources and support data exchange between heterogeneous systems. *UbiDisco* is both a middleware and a collection of user interfaces for service discovery.

UbiDisco hinders the user from the complexity of configuring technical details by means of *discovery actions*. The user can link two systems by reading a barcode or RFID tag which identifies the device/service and provide technical details for the configuration of the link. For example *CroMAR* running on an iPad can be linked to *WATCHiT*, by reading a barcode printed on the device hardware. In this way *WATCHiT* and *CroMAR* network addresses and protocols in use are exchanged between the two systems. *WATCHiT* becomes a data provider for *CroMAR* until a new *discovery action* links *WATCHiT* to a new system (e.g. another instance of *CroMAR* or *Trainer*).

7 Contributions

The contributions of this PhD work are presented according to four areas:

1. Implementation and evaluation of MIRROR Computer Supported Reflective Learning (CSRL) theory
2. Knowledge about designing experience-capturing tools for crisis workers
3. Novel sensing-based interaction techniques to support re-creation and generation of work experience in crisis training
4. Knowledge about implementing prototypes to be deployed into the wild

Contribution 1 maps CSRL theory with applications of technology, contribution 2 provides design challenges for experience-capturing tools, contribution 3 relates to the design of novel interaction techniques to fit systems' requirements emerged during field studies. Finally contribution 4 sheds the light on challenges for rapidly implement design ideas in working prototypes.

Table 7.1 summarises the contributions provided by the papers.

Table 7.1: Papers' additions to the contributions

	Contribution 1	Contribution 2	Contribution 3	Contribution 4
Paper 1			•	
Paper 2	•	•		
Paper 3		•	•	•
Paper 4	•			
Paper 5			•	•
Paper 6	•			
Paper 7				•

7.1 C1: Implementation and evaluation of MIRROR Computer Supported Reflective Learning (CSRL) theory

Contribution 1 of the thesis comprises new knowledge about how theoretical concepts in the CSRL model (Chapter 3) can be mapped to technologies and implemented in artefacts. The work provided successful applications of sensing-based technology, in crisis training, that constitute an empirical evaluation of the model itself.

The CSRL model developed by Krogstie et al. (2013) (Figure 7.1), presents a cycle of four stages to conceptualise reflection at work. For each stage a set of reflection-useful activities that can be enhanced by technology are presented.

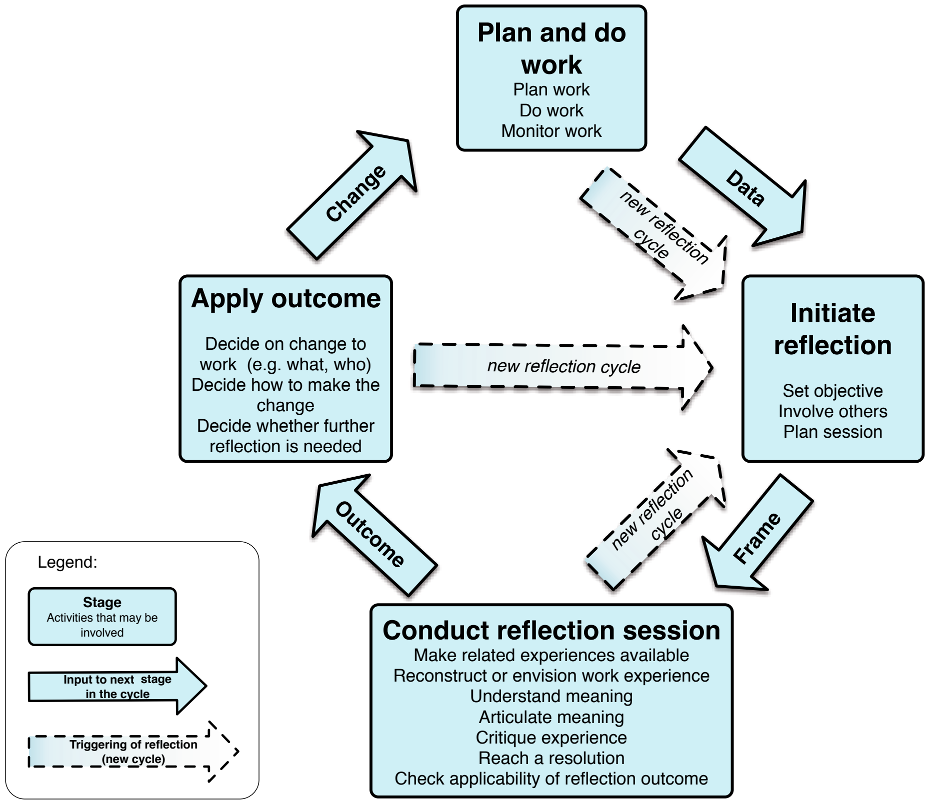

Figure 7.1: CSRL reflection cycle. Figure adapted from (Krogstie, Prilla and Pammer 2013)

During this PhD research specific activities from the four stages of the model have been supported with technology tools (Table 7.2).

Table 7.2: Instantiation of the CSRL model

Stage	Activity	Technology	Prototype
Plan and do work	Do work	Digital board game	*Don't Panic*
	Monitor work	Wearable computers	*WATCHiT*
Initiate reflection	Involve others	Mobile augmented reality	*CroMAR*
Conduct reflection session	Make related experiences available		
	Reconstruct or envision work experience		
	Understand meaning		
	Articulate meaning		
	Critique experience		
Apply outcome	Decide on change to work		
	Decide how to make the change		

Although different prototypes focus on supporting different activities, they can be combined (thanks to the system in P7) in order to provide full support to the CSRL cycle.

During the *plan and do work* the *monitor work* and *do work* activities have been supported. The *monitor work* activity has been implemented by *WATCHiT* (P3) which empowers workers for capturing a wide spectrum of qualitative and quantitative data. I found out that wearable sensor technology and embodied user interfaces provide the best design choice for data collection. The *do work* activity has been supported by *Don't Panic* (P4, P5), by generating realistic work experience that push workers towards taking actions common of real work and under stress conditions in a game environment. Although the *do work* phase in the model describes real work activities, for the specific case of crisis management we claim it can also be applied to simulated work. Indeed, the interactive digital board game technology presented in P5 was effective in recreating stress conditions similar to real work and collaboration affordances typical tho the ones observed during field studies.

CroMAR (P1) supports a wide range of activities. It *involves others* by providing functions for synchronous collaboration. It makes *related experiences available* by aggregating data from multiple sources, including work experience of colleagues (captured by *WATCHiT*), social networks and open data. Then *CroMAR* allows for visualising data while being situated in a physical context that helps to *reconstruct or envision work experience*. By allowing layering and filtering of data according to source, time and space it facilitates to *understand and articulate meanings*. Finally an embedded text editor allows for the collection and sharing of lesson learnt and to elaborate a plan to *apply reflection outcomes*. Thanks to the experience with *CroMAR* we also found out that mobile augmented reality technology is efficient in supporting debriefing and reflection after crisis work.

Contribution 1 can be a resource for researchers in the field of computer supported reflective learning that strive in finding solutions to map theory tools to technologies that people can use at work. Although the applications developed are tailored to the crisis training domain, they could be repurposed for other domains. The need for pervasive data collection tools and disruption-free interfaces is shared by many work practices; the digital board game approach developed in P5 has been proven to be a useful tool also in generating realistic work experience for the dementia care domain, as investigated during research work abroad (see Appendix B). A new application domain for mobile augmented reality technology is found: to support debriefing. *CroMAR*, the tool developed in P1, could be adapted to support debriefing of work practices that share similarities with the crisis domain. The presented technology tools constitute an empirical evaluation of theory which outcomes can inform future development of the CSRL model. Finally a new approach to the design of technology to turn unstructured context data into learning contents was presented in P6 and evaluated across two cases studies. The approach aims at extending the body of knowledge in computer supported reflective learning.

7.2 C2: Knowledge about designing experience-capturing tools for crisis workers

Contribution 2 of this thesis is a set of challenges for the design of experience-capturing tools during real or simulated crises.

Seven design challenges derived from multiple user studies with crisis workers, have been reported in P3. The challenges are summarised in Table 7.3. The challenges shed light on *what* information is relevant and *how* to capture relevant information. This contribution also highlights a design trade-off common for many sensing-based applications: the degree of data that can be captured with sensors, automatically and without user intervention, versus information that can be submitted in-action by workers themselves; which, in the case of crisis training, requires novel interaction approaches (Contribution 3).

The challenges have informed the design of *WATCHiT*, a modular data capturing tool (P3) that has been successfully evaluated in a scenario to support debriefing after procedural training (P2). *WATCHiT* can be configured to address new scenarios, data captured can be also used to support coordination of work and monitoring of activities in real time.

Contribution 2 can be a resource for computer scientists aiming at designing technologies for pervasive quantitative and qualitative data collection. The presented challenges constitute a foundation for the design space for data capturing tools.

They are an expression of the trade-off between technology-centred quantitative data acquisition and user-centred qualitative information collection.

7.3 C3: Novel sensing-based interaction techniques to support recreation and generation of work experiences in crisis training

Contribution 3 of the thesis brings novel interaction techniques to the field of sensing-based interfaces.

The interaction techniques developed assist different tasks.

During *capturing work experience* the focus is on empowering users for collecting work experience without disrupting the work (due to foreground interaction with the capturing tool). Building on prior works on mnemonic shortcuts (Guerreiro, Gamboa and Jorge 2008) and body-centric interaction (Chen et al. 2012) in P3 a novel disruption-free user interface is presented. It allows to use predefined body areas and objects as mnemonic shortcuts to activate sensors and to tag quantitative data with user-predefined information.

To enhance *re-creating work experience CroMAR*, the system presented P1, leverages mobile augmented reality (MAR) to enable visualisation and manipulation of reflection-useful information while being co-located in a physical context. In the implemented system the use of MAR technique has been proven successful in triggering reflection (P2). Moreover usability issues typical of MAR applications (e.g. information overloading or occlusion visualising huge datasets) have been tackled by providing mechanism for filtering the information visualised according with time and source.

Finally during *generating working experience*, tangible user interface frameworks have driven the design of the digital board game presented in P4 and P5. Board game mechanics have been functional to generate realistic work experience in terms of collaboration affordances and decision making. In this setting the use of tangible and sensing-based interaction added realism to the experience and increased players engagement and fun. The game design presented in P4 has been generalised in a approach and design process, presented in P5, that will drive the creation of future digital board games.

Contribution 3 can be a resource for interaction designers interested in creating interfaces for disruption-free data collection of experiences, situated data visualisation and simulated interactive experiences. The interaction techniques developed can be translated to new application domains.

Table 7.3: Design challenges for data collection tools in crisis work

	Challenge	Description
DC1	Mobility of work and sensing	It is important to complement data from sensors embedded in the environment with mobile ones. The degree of mobility and thus granularity of data is important. Fine granular data is achieved with sensors worn by crisis workers.
DC2	Different crises, different relevant data	Being each crisis unique, it is difficult to define which data might be relevant to capture based on generic typologies of crises.
DC3	Different types of data	Different types of information are relevant to be captured. Including information for assessment of the worker's safety, for mapping the territory and the work and information related to the rescued (e.g. type of injures).
DC4	Sensor data and user-submitted data	To complement quantitative data, workers might provide qualitative data that cannot be measured with sensors (e.g. derived from experience).
DC5	Different use, different sharing	While data for coordination of work and safety (e.g. the location of agents) should be shared automatically, sensitive data useful for personal reflection (e.g. stress levels) shouldn't be shared without the user's direct consent.
DC6	Intuitive, hands-free interaction	Workers must focus on the rescue operation and not on capturing data and logging tasks. User interfaces must be intuitive and provide distraction-free interaction.
DC7	Automate and discrete capturing	Capturing data with automatic means doesn't require user intervention but it produce datasets often affected by noise. Discrete capturing requires the user to activate sensors but produces more relevant and contextualised data.

7.4 C4: Knowledge about implementing prototypes to be deployed into the wild

Contribution 4 brings new knowledge derived from the author's experience in constructing prototypes of hardware and software systems. Prototypes were developed from the early phases of the research work to be used as demonstrator of tools for data collection (C2) and novel interaction techniques (C3). Also, ecologies of prototypes were functional for the evaluation of the CSRL model (C1), when more than one prototype was orchestrated in order to support part of the CSRL cycle.

Eight prototyping iterations have been developed as part of this thesis. Each of them involved a mix of software, hardware and material design. From a software engineering point of view, the challenges consisted in making heterogeneous systems to discover each other and exchange data over a common protocol. This challenge has been addressed by the *UbiDisco* middleware developed in P7. Most of the prototype featuring embedded hardware, I iteratively developed relatively complex electronics; for example to sense data from the environment or to provide haptic and visual feedbacks. I employed a wide range of technologies and toolkits which were not designed to be integrated, highlighting potentiality and limitations of state of the art technology for embedded systems. For example, the system of P5 involved the use of three different hardware toolkits and programming languages, and a bit of hacking. This attitude hacking and tinkering existing toolkits has been required because a product to fully fulfil the implementation of requirements of our system was not available on the market. Yet this is a resource for hardware engineers willing bring advances in the state of the art of toolkit for building electronics. To this purpose a list of toolkits that have been used or reviewed during the work is provided in Appendix C.

Prototypes used by crisis workers, in-action, have to be built for higher resilience compared to digital artefacts developed for lab testing. The physical simulations of crisis work in which we staged our systems' evaluations were designed to recreate conditions as close as possible to real emergencies; including exposure to physical and thermal shocks. This setting has required the prototyping process to move one step closer to product engineering. The final stage of prototypes feature 3D-printed and laser-cut enclosures to shelter the electronics from the environment. Moreover for iteration after iteration the size of the prototypes has shrunk. For example the wearable technology in P3 have reached in four iterations a size compatible for being comfortably worn underneath work uniforms.

Contribution 4 is a resource for hardware and software engineers. Also it serves at case study for researcher to investigate the design of hardware and software toolkits to assist prototyping of electronic inventions.

8 Evaluation

This chapter provides an evaluation of the contributions of the thesis with respect to research questions. In addition, validity threats are discussed.

8.1 Evaluation of research questions

8.1.1 MRQ: What are the opportunities introduced by combining reflective learning theories with sensing-based interfaces for supporting crisis training?

The main research question is answered by Contribution 1-4. Using crisis training as case study for design research, it is demonstrated how conceptual tools from theory in CSRL can be implemented in a suite of applications of sensing-based technology: *WATCHiT*, *CroMAR*, and *Don't Panic*. Each application assists specific activities which the CSRL model has identified to be relevant for reflection. Two or more applications can be configured to work together in an ecology, in order to address the interrelated nature of CSRL activities in terms of sharing of data and reflection outcomes. In this way it is also addressed the need for supporting the range of scenarios workers train for by means of loosely coupled, modular applications.

8.1.2 RQ1: How sensing-based interfaces can be designed to enable unobtrusive experience collection during crisis work?

This question is answered by Contribution 2 and Contribution 3. C2 has identified a set of challenges for the design of experience-capturing tools, focusing on *what* data to collect and *how* to collect it. One of the identified challenges, the need of intuitive and hands-free user interfaces for controlling the capture of information, has been further addressed by C3 with the design of a novel user interface for controlling the data capture process.

8.1.3 RQ2: How sensing-based interfaces can be designed to trigger and support reflection activities?

This question is answered by Contribution 3. It is found that theories in the field of tangible, embodied and embedded computing can drive the design of sensing-based interfaces either to *capture work experience* and to *generate work experience*. The specific techniques adopted are derived from sensing-based interaction including mobile augmented reality, tangible and embodied interaction. Once more it is not a single interaction modality that has been proven to be useful in designing ICT support for reflection but rather a mix of different technology-assisted experiences.

8.1.4 RQ3: How sensing-based interfaces for supporting reflection can be rapidly prototyped?

This question is answered by Contribution 4. It is found out that prototyping sensing-based interfaces for supporting reflection require a wide range of skills ranging from software and electronic engineering. Yet a toolbox for assisting in full the work of designers and engineers in implementing functional requirements in prototypes could not be identified. Despite that, recent advances in open source hardware and software, digital manufacturing and technology developed by the author (P7) allowed the author to build working prototypes robust enough to undergo evaluations during simulated crisis work. Still the production of prototypes requires resources and skills not usually required for prototyping "traditional", ICT systems.

8.2 Evaluation of research approach

The research approach taken in this thesis has some limitations. In this section validity issues (Yin 2013) are discussed.

8.2.1 Construct validity

Construct validity assess whether correct operational measures for the concepts being studied have been adopted.

In this work the impact on reflective learning for the technology tools developed was evaluated (as proof of validity for C1). Also due to the novel nature of the user interfaces developed, technology acceptance tests and usability evaluations have been performed.

Considering the design research approach taken and the number of human factors involved, methods from qualitative research were used in the evaluations. The methods used included observations, semi-structured interviews, and questionaries. The adoption of the MIRROR Evaluation Toolbox (Renner and Wesiak 2014), which provides questionnaires to measure reflective learning at work, straighten the conclusion validity of the research. These questionnaires are built on the

Kirkpatrick framework (Kirkpatrick and Kirkpatrick 2009) and have been developed in cooperation with participants from different workplace settings.

The number of participants in the studies added up to 56 crisis field workers (e.g. firefighters, paramedics), 1 disaster manager, 8 IT students and 4 HCI experts. Among the field workers 5 participants attended more than one study. The size of data samples used for statistical analysis is therefore limited and it weakens the conclusion validity. Furthermore most of evaluation studies lasted only for a short time. It is therefore not possible to prove long-term learning effects for the tools developed.

8.2.2 Internal validity

Internal validity questions whether the method used proves casual relationships between two variables or not.

By running field studies during physical simulations arranged by external organisations, some variables could not be controlled. Gather access to people for the studies has proven to be challenging. Training exercises aimed at re-creating aspects of stress and unpredictability typical of real emergencies, for this reason workers were not always able to share information with researchers. The time of the events set apart for debriefing and collaborative reflection was also very limited. During field studies it has been sometime required to deviate from the agreed protocol due to the planned and unplanned unpredictability of such events.

Despite those challenges I was able to gather enough information to complete design work. During field studies, the lack of control was traded for realism. Events attended recreated working conditions as close as possible to real emergencies. Participants were unaware of the type of emergency to face until the very last moment, human mistakes and failure of technical systems were re-created on purpose by the event manager. Finally, during the observed events, volunteers acting as injured were made-up with fake wounds and instructed to behave accordingly (e.g. panicking). Considering the very situated nature of crisis work, the widespread layout of activities in space, the coexistence of multiple roles and organisations, choosing field studies over an experimental strategy has strengthen the internal validity of the work.

8.2.3 External validity

External validity questions whether the the study's findings can be generalised to other settings.

Given the characteristics of the sample of population the research has been evaluated with, it is not possible to draw conclusions about generalisations of results, both within the crisis domain and for other settings.

Being participants of field studies performed affiliated to a small set of crisis response organisations; the design research has been case studied on the specific needs of those organisations. Although a review of literature have shown that technology requirements found in our user studies are common to other organisations in different countries, it is not yet evaluated how the results from this work could be accepted by other organisations. Contacts with external organisations have been established in order to evaluate generalisation of results as part of future work.

Second, it has not been extensively investigated how results from this PhD could be translated to work practices that are different than the crisis domain. The novel interaction techniques and the rapid prototyping approach developed have been employed to create games for training workers in dementia care homes for better care, during a research visit abroad. The same approach drove the design and implementation of tangible interface to promote user engagement and reflection about urban-mobility data, as part of a second research visit abroad (Appendix B)

8.2.4 Reliability

Reliability is the extent to which another researcher would find the same answers.

Data were recorded and analysed by at least two persons. Some of the data were analysed by more than two people. Further, different researchers have lead the work for different studies. This suggests that the reliability is satisfactory.

9 Conclusions and future work

This thesis has focused on enhancing crisis training practices with novel sensing-based technologies to capture, re-create and generate crisis work experiences.

The main research method adopted was design science. To this respect six field studies during physical simulations of crisis work were performed. Field work and literature in computer supported reflective learning has driven eight prototyping iterations during which fairly complex hardware and software sensing-based devices were built and evaluated both in focus groups and on the field. The work has resulted in seven papers published and five declarations of inventions filed for technology transfer.

The research questions were answered by four contributions, hereafter summarised in a set of conclusions which delineate future work.

Conclusion 1

The MIRROR CSRL model (Chapter 3) can be used to technology-enhance reflective learning practices in crisis training. Activities described in the model together with requirements derived from field studies drove the design of sensing-based interfaces to support the capture, re-creation and generation of work experiences. Three prototypes, including wearable data-collection tools (P3), mobile augmented reality browsers (P1) and serious games (P4,P5), were built in eight iterations. Ecologies of prototypes were successfully evaluated for their impact in supporting debriefing after physical simulations of crisis work (P2). New theories about the use of sensor data as learning content emerged (P6).

Further work is required to map with technology the activities in the model not directly addressed in this research work. As evaluated in Chapter 8, the investigation in this thesis is deeply connected with the specific case of crisis work. Future work will generalise the theoretical findings and the technologies produced to other domains.

Conclusion 2

Capturing relevant data to feed reflection processes is challenging due to the unpredictability of relevance typical of reflection (P6). In addition, the highly dynamic nature of crisis work requires to design tools to be adapted to the needs of always varying scenarios. This space of opportunities is provided to researchers as a set of challenges to the design of experience-capturing tools (P3). The challenges were explored with the development of data collection tools that can be used to support debriefing (P2). Prototypes developed feature wearable sensors and an embodied user interfaces based on mnemonic body shortcuts.

Further work is required to validate the identified challenges with more field work and to investigate challenges not addressed in this work with the production of new prototypes. Furthermore the relevance of the challenges to other application domain has to be investigated.

Conclusion 3

Novel techniques inspired by the field of tangible, embodied and embedded computing can facilitate interaction with technology to support reflection. The approaches have driven the design of interfaces to reduce distraction while interacting with capturing tools during work, to allow for browsing information in physical environments that contextualise reflection; and to provide social and engaging serious gaming experiences.

Further work points at validating the developed approaches with the production and evaluation of new prototypes; and to further formalise interaction models and design processes.

Conclusion 4

Prototypes have a central role in design science research for the validation of theories and in the development of new methods. Yet, prototyping sensing-based interfaces require large efforts due to the wide range of skills required, including hardware and software engineering, material design and assembly. Further, technology artefacts to be tested during crisis work are to be built for higher resilience compared to the ones deployed for lab testing. Despite prototyping toolkits are available, to date no holistic tool to support the development of both software and hardware complex features could be identified. This has resulted in large efforts required for building prototypes and in the development of a understanding of the challenges and tools currently available.

Future work builds on the challenges experienced with the production of prototypes for this PhD work for the conceptualisation and production of a toolkit to ease the production of complex sensing-based systems.

In conclusion, this thesis has developed knowledge about the implementation of computer supported reflection theories into novel ICT systems and sensing-based interfaces that can produce learning outcomes. Although the investigation is limited to the characteristic case of crisis training, the basis for the generalisation of theories and technologies developed has been settled during research work done in foreign institutions (Appendix B). Commercial exploitation of research outcomes is being explored, research funds have been granted to this purpose (see Section 1.4.3). Future work aims at generalising research findings to new domains and commercially exploit research results.

A Secondary papers

In this appendix papers which are not included in the PhD thesis are briefly summarised. The papers present work-in-progress or incremental achievements that have led to the research results reported in the thesis.

Each summary includes:

- Title
- Authors
- Where the paper was published
- Brief description of the paper's contribution

Paper 1

Title: WATCHiT: Towards wearable data collection in crisis management

Authors: Simone Mora and Monica Divitini

> *Abstract:* In this paper we present the work-in-progress on WATCHiT, a wristband computer for data collection during crisis response work. We outline the user-centered research methodology we adopt and we identify four design challenges to be tackled. We report the design of a working prototype that relies on wearable sensors to capture quantitative data and on an eyes-free, token-based interface for tagging sensor data with user-defined text messages. The prototype has been evaluated with emergency workers during a simulated rescue operation.

Published in: Work-in-progress at the Eight International Conference on Tangible, Embedded and Embodied Interaction (TEI), 2014.

Description: The papers present a first draft of the design challenges for experience-capturing tools and a description of a early prototype of *WATCHiT*.

Paper 2

Title: Supporting Crisis Training with a Mobile Game System

Authors: Ines Di Loreto, Emil Mork, Simone Mora and Monica Divitini

Abstract: Crisis training is highly complex and it requires multiple approaches. Games have a high potential in this context because they might support players in exploring different situations and experience different crisis scenarios. This paper proposes a mobile game system for crisis training. The system aims to promote soft skills and basic procedures learning. The system is composed by (i) a website that allows to set up the game and review game results and (ii) a mobile game. The set up supports the tailoring of games that better fit the specific learning needs of the players. The actual play promotes gaining of experience. The final review is intended to promote reflection on the gained experience, mirroring debriefing sessions that are common in crisis situations. Results from the initial evaluation show that the game and the post-game reflection are useful to train soft skills and to improve behavior.

Published in: Proceedings of the International Conference on Serious Games Development Applications (SGDA), 2013.

Description: The game presented in the paper is a mobile version of the *Don't Panic* board game, aiming at providing alike learning objectives, yet via a collaborative pervasive gaming experience.

Paper 3

Title: Token-based Interaction with embedded digital information

Authors: Simone Mora

Abstract: Embedding digital information into places and objects can improve collaborative processes by allowing a piece of information to travel across different contexts of use. Yet tools for supporting the processes of information embedding, discovery and visualization are needed. This PhD-work aims at providing a conceptual framework that promote the use of (in)tangible tokens to enable information embeddedness. The framework is used to drive the design of pervasive applications to support collaboration and reflection in crisis management.

Published in: Doctoral consortium of the International Conference on Tangible, Embedded and Embodied Interaction (TEI), 2013.

Description: This paper details a work-in-progress on the research questions and methodology adopted throughout this PhD work. It also describes mid-term contributions.

Paper 4

Title: Tangible and Wearable User Interfaces for Supporting Collaboration among Emergency Workers

Authors: Daniel Cernea, Simone Mora, Alfredo Perez, Achim Ebert, Andreas Kerren, Monica Divitini, Didac Gil de La Iglesia and Nuno Otero

> *Abstract:* Ensuring a constant flow of information is essential for offering quick help in different types of disasters. In the following, we report on a work-in-progress distributed, collaborative and tangible system for supporting crisis management. On one hand, field operators need devices that collect information, personal notes and sensor data, without interrupting their work. On the other hand, a disaster management system must operate in different scenarios and be available to people with different preferences, backgrounds and roles. Our work addresses these issues by introducing a multi-level collaborative system that manages real-time data flow and analysis for various rescue operators.

Published in: Proceedings of the CRIWG Conference on collaboration and technology, 2012

Description: This paper presents the first investigation to the use of wearable sensors for data-capture during crisis work. Although the scenarios reviewed by the paper don't focus on training, a prototype of a multipurpose wearable sensor is presented and integrated with an existing system for crisis management. The prototype will be later repurposed to assist crisis training scenarios and renamed *WATCHiT*.

Paper 5

Title: Collaborative Serious Games for Crisis Management: An Overview

Authors: Ines di Loreto, Simone Mora and Monica Divitini

> *Abstract:* Training in the field of crisis management is complex and costly, requiring a combination of approaches and techniques to acquire not only technical skills, but also to develop the capability to cooperate and coordinate individual activities towards a collective effort (soft skills). In this paper we focus on serious games for increasing participants' skills in a playful manner. In the paper we identify general issues characterizing crises management and we analyze the state of the art of serious games

for crisis management in order to understand strengths and weaknesses of these environments.

Published in: IEEE International Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE), 2012

Description: The paper presents a literature review in the field of serious games for supporting crisis training. The paper also provides a set design suggestions that will be addressed with the development of *Don't Panic*.

Paper 6

Title: Mobile and Collaborative Timelines for Reflection

Authors: Anders Kristiansen, Andreas Storlien, Simone Mora, Birgit R. Krogstie and Monica Divitini

Abstract: In this paper we present the design and evaluation of TimeLine, a mobile application to support reflective learning through timelines. The application, running on Android devices, allows users to capture traces of working and learning experiences in a timeline with the aim to provide data that can be used to promote reflection and learning after the experience. The paper presents the design of the application, its evaluation, and identifies challenges connected to the development and deployment of timelines for reflection.

Published in: Proceedings of the IADIS International Conference Mobile Learning.

Description: The paper proses the use of timelines to capture and visualise traces of working experiences, with the goal to promote reflective learning. Based on the work in this paper, the use of the timelines will be later integrated with augmented reality approach in the design of a mobile app, *CroMAR*, to support in situ debriefing after crisis work.

Paper 7

Title: Supporting Mood Awareness in Collaborative Settings

Authors: Simone Mora, Veronica Rivera-Pelayo and Lars Müller

Abstract: Affective aspects during collaboration can be exploited as triggers for reflection, yet current tools usually ignore these aspects. In this paper, we present a set of design choices to inform the design of systems towards enabling mood awareness in collaborative work settings like meetings or conferences. Design choices have served to outline and implement a collection of prototypes, including two input interfaces and three visualizations, which have been evaluated during an important project meeting over three days. Our results show that (a) the user acceptance of capturing mood is high (b) the aggregated mood values are related to the work process and (c) aggregated moods can influence the individual by creating awareness of others. Further discussion on the impact of the different design choices shows promising venues to improve mood awareness support.

Published in: Proceedings of the International Conference on Collaborative Computing (CollaborateCom), 2011

Description: This paper investigates the capture and visualisation of moods and emotions as triggers for reflection. Keeping track of emotions experienced by workers is critical in crisis management and training. Supports for capturing moods it has been further integrated in *WATCHiT*.

B Research abroad

During the PhD I was a as visiting researcher in two foreign institutions: *City London University*[1] in London (UK) and *MIT SENSEable City Lab*[2] in Cambridge, MA (USA). The purpose of the two visits was to investigate whether the technologies developed during the PhD could be generalised to application domains that share similarities with crisis training.

B.1 City London University

During fourteen weeks spent as a visiting fellow at City University I investigated the design and production of *Hazel Court*, a digitally augmented serious game for training of dementia carers for better care. I worked under the supervision of Professor Neil Maiden. A working prototype of *Hazel Court* (Figure B.1) has been implemented and evaluated in eight care homes in the greater London area. The game design and underpinning theories are reported in a joint publication to be submitted. This experience strengthened my competences in building sensing based-interfaces to support reflection in a domain which shares similarities with crisis training. It added to the study of RQ2 and RQ3.

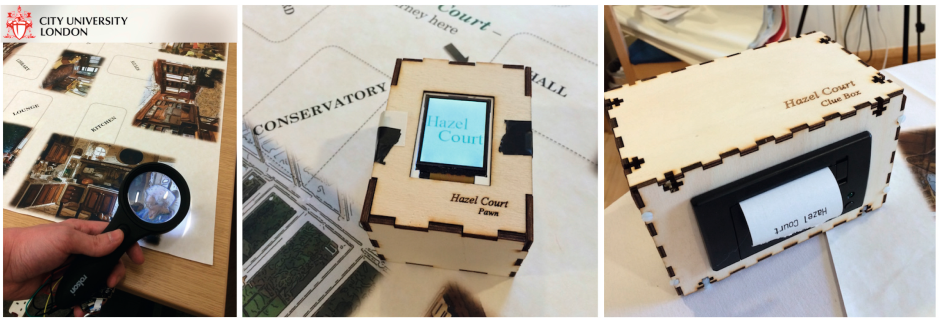

Figure B.1: The Hazel Court prototype

[1] City London University - http://city.ac.uk
[2] MIT SENSEable City Laboratory - http://senseable.mit.edu

B.2 MIT SENSEable City Lab

During twelve weeks spent as a visiting fellow at the MIT SENSEable City Lab I investigated the design and production of a tangible interface to promote user engagement and reflection about urban-mobility data. I worked under the supervision of Professor Carlo Ratti. A working prototype of *DriveWAVE* (Figure B.2) has been implemented. DriveWAVE is a tangible interface that allows casual players in public spaces to challenge a computer brain against managing car flows towards minimising pollution and avoiding traffic jams. The installation aims at sparking the interest in future sustainable cities[3]. The prototype features sensing-based interaction with the audience via presence sensors, physical controllers and digital projections. The work has been displayed to the public in two exhibitions: "Wave" held in Paris and "CNR Internet Festival" held in Pisa, Italy. This experience straightened my competences in building complex sensing-based systems to be deployed in public settings and added to the investigation of RQ3.

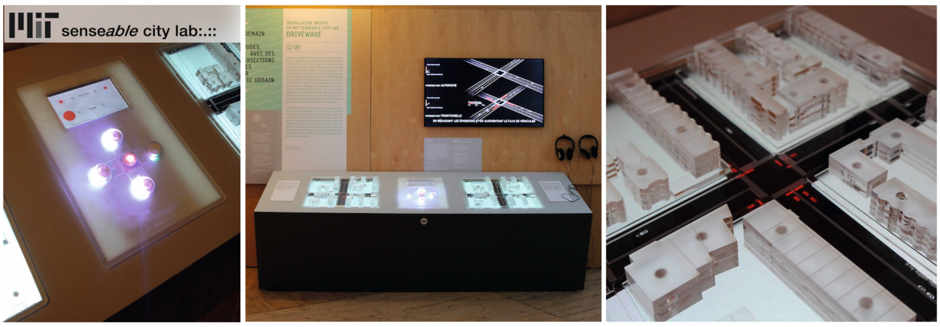

Figure B.2: The DiveWAVE prototype

[3]For more information please visit http://senseable.mit.edu/wave/

C Toolkits for prototyping of sensing-based interfaces

This appendix catalogue selected toolkits to ease prototyping of hardware and software features of sensing-based interfaces. A toolkit usually is composed by a mix of electronic circuitries, components, software libraries and communities of users willing to share knowledge implementation details of prototypes being built.

The list reported in Table C.1 has been used to select relevant tools to build the prototypes developed during the PhD work and it can be employed to drive future design iterations. The toolkits hereafter reported have been selected after surveying, and in some case trying out, development tools either already available as commercial products or being available for beta testing.

Toolkits are classified along four dimensions, chosen to support challenges and requirements commonly found in the development of sensing-based interfaces:

- **Modularity:** whether the tool allows to build transient electronic circuitries without requiring soldering or high-level expertise in electronic engineering. For example by means of wired or wireless plug-and-play modules.
- **Connectivity:** whether the tool allows to effortlessly build internet-enabled prototypes by embedding wireless transceivers operating with standard protocols. For example providing ready to use bluetooth or wifi connectivity.
- **Ecology:** whether the tool provides guidelines and mechanisms to build applications that orchestrate a network of heterogeneous artefacts to provide a common functionality. For example to enable distributing user interaction on a number of different interfaces yet providing a consistent user experience.
- **Visual programming language:** whether the tools allows programming features using visual or other metaphors to speed up the development of software.

In the following, Table C.1 details the toolkits reviewed. Rather than providing an exhaustive list of solutions the aim is at giving reference to tools that somehow address the prototyping challenges found in this PhD work.

Table C.1: List of toolkits for rapid prototyping of sensing-based interfaces

Name	Price	Released	Open source	Modul.	Connect.	Ecology	Visual language
Arduino [1]	$30	2005	yes	yes (tinker kit)	yes (w/extra hw)	no	yes (ar-dub-lock)
RaspberryPi [2]	$40	2012	yes	no	yes (w/extra hw)	no	yes (scratch)
LittleBits [3]	$100	2008	yes	yes	yes (wifi)	no	no
Lightblue Bean [4]	$30	2013	partially	no	yes (ble)	no	no
Printoo [5]	$45	2014	yes	yes	yes (ble)	no	no
Bitalino [6]	$45	2014	n/a	yes	n/a	no	no
Atomwear [7]	$45	2014	yes	yes	yes (ble)	no	no
Microduino [8]	$20	2013	yes	yes	yes (BT)	no	no
Twine [9]	$99	2012	n/a	no	yes (wifi)	no	no
Microview [10]	$45	2014	partially	no	no	no	no
Xadow [11]	$30	2012	no	yes	yes (ble)	no	no
Kano Computer [12]	$99	2013	partially	no	yes (wifi)	no	yes (scratch)
Spark [13]	$39	2013	partially	no	yes (wifi)	no	no

Continued on next page

Name	Price	Released	Open source	Modul.	Connect.	Ecology	Visual language
Wonderbar [14]	$100	2013	no	yes	yes (ble+wifi)	n/a	yes
Metawear [15]	$35	2014	no	no	yes (ble)	no	no
Smart Citizen [16]	$100	2012	no	partially	yes (wifi)	no	no
Circuit Scribe [17]	$30	2014	no	yes	no	no	no
Verve 2 [18]	$45	2014	n/a	yes	no	no	n/a
Notion [19]	$99	2014	no	yes	no	no	no
Make!Sense [20]	$39	2014	no	yes	no	no	yes (scratch)
McThings [21]	$100	2014	n/a	yes	yes (ble+wifi)	no	yes
Gadgeteer [22]	$100	2009	no	no	no	no	no
Intel Edison Sparkfun Blocks [23]	$120	2015	no	yes	yes (ble+wifi)	no	no
Mesh [24]	$105	2015	n/a	yes	yes (ble)	yes	yes
Spark Photon [25]	$19	2015	n/a	no	yes (wifi)	no	no
Airboard [26]	$20	2015	no	yes	yes	no	no
HIRIS [27]	$100	2015	n/a	yes	yes(ble)	no	no

[1]: http://arduino.cc
[2]: http://raspberrypi.org
[3]: http://littlebits.cc
[4]: http://punchthrough.com/bean/
[5]: http://printoo.pt
[6]: http://www.bitalino.com/
[7]: https://www.kickstarter.com/projects/343910040/atomwear
[8]: https://www.kickstarter.com/projects/microduino/microduino-arduino-in-your-pocket-small-stackable
[9]: https://www.kickstarter.com/projects/supermechanical/twine-listen-to-your-world-talk-to-the-internet
[10]: https://www.kickstarter.com/projects/1516846343/microview-chip-sized-arduino-with-built-in-oled-di
[11]: http://www.seeedstudio.com/depot/s/xadow.html
[12]: https://www.kickstarter.com/projects/alexklein/kano-a-computer-anyone-can-make
[13]: https://www.kickstarter.com/projects/sparkdevices/spark-core-wi-fi-for-everything-arduino-compatible
[14]: http://www.dragoninnovation.com/projects/35-wunderbar-by-relayr
[15]: https://www.kickstarter.com/projects/guardyen/metawear-production-ready-wearables-in-30-minutes
[16]: https://www.kickstarter.com/projects/acrobotic/the-smart-citizen-kit-crowdsourced-environmental
[17]: https://www.kickstarter.com/projects/electroninks/circuit-scribe-draw-circuits-instantly
[18]: https://www.kickstarter.com/projects/54060271/verve2-connect-your-world-to-your-computer-and-int
[19]: https://www.kickstarter.com/projects/1044009888/notion-be-home-even-when-youre-not
[20]: https://www.kickstarter.com/projects/1978340629/makesense-a-universal-interface-for-learning
[21]: https://www.kickstarter.com/projects/2016620887/mcthings-tiny-wireless-bluetooth-sensors-and-contr
[22]: http://www.netmf.com/gadgeteer/
[23]: https://www.sparkfun.com/products/13276
[24]: https://www.indiegogo.com/projects/mesh-creative-diy-kit-for-the-connected-life
[25]: https://www.spark.io
[26]: https://www.kickstarter.com/projects/223628811/the-airboard-sketch-internet-of-things-fast
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Part II

Research papers

D Research Papers

Paper 1 Mora, S., Boron, A., & Divitini, M. (2012). CroMAR: Mobile Augmented Reality for Supporting Reflection on Crowd Management. *International Journal of Mobile Human Computer Interaction*, 4(2), 88–101.

Paper 2 Mora, S., & Divitini, M. (2014). Supporting Debriefing with Sensor Data: A Reflective Approach to Crisis Training. *In Proceedings of Information Systems for Crisis Response and Management in Mediterranean Countries, ISCRAM-MED*, 196(7), 71–84.

Paper 3 Mora, S., & Divitini, M. (2014). WATCHiT: a modular and wearable tool for data collection in crisis management and training. *In Proceedings of the European Conference in Ambient Intelligence, AMI*, 8850(22), 274-289.

Paper 4 Di Loreto, I., Mora, S., & Divitini, M. (2012). Don't Panic: Enhancing Soft Skills for Civil Protection Workers. *In Proceedings of International Conference on Serious Games Development Applications, SGDA*, 7528(1), 1–12.

Paper 5 Mora, S., Di Loreto, I., & Divitini, M. The interactive-token approach to board games. *Ready for submission*.

Paper 6 Müller, L., Divitini, M., Mora, S., Rivera-Pelayo, V., & Stork, W. (2014). Context Becomes Content: Sensor Data for Computer Supported Reflective Learning. *IEEE Transactions on Learning Technologies*, PP(99).

Paper 7 Mora, S., & Farshchian, B. A. (2010). A Unified Architecture for Supporting Direct Tag-Based and Indirect Network-Based Resource Discovery. *In Proceedings of the International Conference on Ambient Intelligence, AMI*, 6439(20), 197–206.

Paper 1

CroMAR: Mobile Augmented Reality for Supporting Reflection on Crowd Management

Simone Mora, Alessandro Boron, and Monica Divitini

International Journal of Mobile Human Computer Interaction

Is not included due to copyright

Paper 2

Supporting Debriefing with Sensor Data: A Reflective Approach to Crisis Training

Simone Mora and Monica Divitini

In Proceedings of Information Systems for Crisis Response and Management in Mediterranean Countries (ISCRAM-MED)

Is not included due to copyright

Paper 3

WATCHiT: a modular and wearable tool for data collection in crisis management and training

Simone Mora and Monica Divitini

In Proceedings of the European Conference in Ambient Intelligence (AMI)

WATCHiT: a modular and wearable tool for data collection in crisis management and training

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Abstract. We present WATCHiT, a prototype of sensor-augmented wristband computer for data collection during crisis response work. During crises, information about the environment (e.g. to map the territory) and the rescuers (e.g. for assessment of workers' condition) offers help to support coordination of work, post-emergency debriefing and to build realistic training scenarios. Being each crisis nearly unique it is important to collect data from every single occurrence, yet it is difficult to foresee the type of data and context information that is relevant to capture. WATCHiT features: (1) wearable sensors, (2) easy customization of the type of information sensed, including both quantitative and qualitative data; (3) an intuitive, distraction-free user interface for controlling the data capturing procedure. Our design process has been driven by user studies during training events characterized by a high degree of realism; our prototype has been successfully evaluated with experts against technology acceptance.

Keywords. Wearable computers; crisis response; crisis training; sensor data; tangible interface

1 Introduction

Capturing information about the condition of the environment and of workers is critical in crisis response, e.g. in case of earthquakes, overcrowding, and flooding. This information might include, e.g. location of rescuers, number of injureds and environmental data (air and soil contamination, temperature).

Information captured from a disaster scene is useful (i) to provide support for decision-making processes along the command chain [1], (ii) to support cooperation among different agents and roles in the field [2, 3], (iii) to inform post-crisis debriefings to understand what happened and learn from mistakes [4, 5]; and (iv) to recreate crisis scenarios in training exercises [6].

User studies [7, 8] report that rescue workers, in particular first responders, currently play a central role in capturing data on action and throughout the duration of a crisis. Agents broadcast over vocal radio communications sensor readings taken by multiple handheld devices (e.g. GPS, Geiger counter); often contextualizing raw data with comments and qualitative observations. In general this practice is prone to error and demanding for workers [7], whose primary focus has to remain on giving assistance to the persons in need. With that, information captured might get biased by factors like attention distribution and impediments in operating tools for data collection while activating rescue protocols (e.g. carrying someone on a stretcher). Those errors affect both the ability to react timely to events and the completeness and correctness of logs to be used in debriefings.

Mobile and wearable sensors could improve information collection on a crisis scene. They have recently moved from being expensive tools to be used under the supervision of professionals in controlled environments; for example for logging human's vital signs in sports or safety-critical jobs, to commercial products for everyone.

Our research started as an investigation on the use of consumer sensors and applications to collect data during crisis exercises, yet our user studies soon revealed that user interfaces in many wearable sensors-based apps featured touch-screens or voice interaction and cannot be used on a crisis scene. Workers wear heavy gloves that make interaction with touchscreen almost impossible, voice-based command might get distorted by noise on the field (e.g. explosions, alarms). Furthermore workers' hands are most of the time busy using tools (e.g. stretchers, cutters or hammers) and concerns were shared about any computer interface that distract from rescue operations.

In this paper we report the design, implementation and evaluation of WATCHiT, a prototype of wearable computer for supporting modular data collection during crisis response work. WATCHiT addresses three requirements gathered during our user studies: (1) it is wearable, (2) it provides easy customization of the type of information sensed, including both quantitative and qualitative data; (3) it provides an intuitive, hands-free user interface for controlling the data capturing process.

Our focus is on data collection, how the data is used goes beyond the scope of this paper. Being data captured with WATCHiT broadcasted using standard protocols it is possible to complement existing systems for decision support (DSS) and tools for supporting debriefing, like [9].

In the following sections, after related works, we present the research methodology that lead to the current prototype of WATCHiT. We then describe design challenges we identified, followed by the final prototype implementation and evaluation. We conclude the paper tracing out future works.

2 Related works

Research in hardware development in the field of pervasive computing, has brought to a degree of miniaturization that allow for embedding sensors in garments like wristbands, shirts and socks. While usually a sensor module is designed to work out-of-the-box for a specific application domain just a few works have focused on modularization and customization of data collection tools.

In [10] Zehe et al. created a toolkit for rapid prototyping of wearable sensing applications using sensors embedded in LEGO bricks that can be stacked on top of a base module and communicate information wirelessly to a server. Their focus is in automatic sensing and logging of information like body movements and environmental data. Aiming at simplifying the design process of sketching sensor-based modular applications, DUL radio modules [11] are small hybrid modules able to capture and broadcast data from sensors connected to them; while [12] presents a software and hardware toolkit that allow non-experts to experiment with building different sensors applications.

Due to the reduced size and limited capability of information display, wearable computers require novel interaction techniques. Several works investigated the use of "Body-centric interactions" [13] in order to exploit body movements for interaction. In [14] Pasquero et al. investigate exploiting eyes-free active tactile interactions on a wristband prototype for acquiring information from a companion mobile device. The wrist is used as an anchor point over to perform hand gestures like cover-and-hold, shake and swipe. Similar to this work, the "Gesture watch" [15] investigates contact-free hand gestures over a watch-like device to control media players. Getting more physical, the Stane project [16] investigates scratch, rub and tap gestures over a textured surface, to control another device like a mobile phone or a music player. While the above-mentioned projects use the wrist or a surface as anchor points for gestures recognition, [17] exploits free-form forearm gestures in the air captured by a accelerometer embedded in a armband. They experimented with 12 different specific gestures commands achieving a relatively high recognition rate, considering the use of a single 3-axis accelerometer sensor. Yet none of those related works directly address data collection during crisis nor the need of distraction-free user interfaces.

3 Research approach

WATCHiT has gone through three user-centered design iterations. User studies and tool evaluations were conducted during simulated crisis events organized for training purposes. Although traditional field studies claim that a work practice is best understood observing the real environment [18], there are issues associated with doing ethnography and testing technology in settings characterized by traumas and emergencies [19], such as hospitals and crisis scenes. Moreover real crisis poses researchers' safety at risks and are largely unforeseeable in time and space. The simulations we base our field study on are organized to provide a high degree of realism, involving dozens of agents; and to recreate working conditions that are as close as possible to real crises.

Data collected during the studies included video recording of parts of the events, notes from one observer, and interviews.

The two first versions of WATCHiT we developed acted as technology probes [20]. Despite their usability issues, they were essential for us and for users to create new scenarios and identify technological challenges.

3.1 User studies

During the first design iteration we performed observation and shadowing of emergency workers during a three-days simulation emergency response work held in Italy, in October 2011 (Figure 1-a). Different crisis scenarios were simulated both at daytime and nighttime, including flooding, earthquake and a massive car crash. The simulation involved different units (ER units, civil protection, police, dog units, …), and people with different roles (disaster managers, team coordinators, volunteers, injured figurants, …). The simulation was conducted in a physical environment that resembled as much as possible a real emergency (e.g. broken trees, debris, broken cars). Rescue exercises involved in sequence: police forces to handle traffic and fence the operation area; firefighters to explore and secure undisclosed areas; dog units to search for survivors; and paramedics to activate triage and medical assistance. ICT support for sharing information such as check-in locations, activities or sensor data readings was limited to vocal audio transceivers (also known as walkie-talkies). Some agents were furnished with handheld sensors for hazardous gas and for acquiring GPS traces. Those devices did not share a common user interface nor communicate data automatically. Call dispatchers in a coordination room were in charge of logging radio communications and of updating a digital map with the location of team of workers.

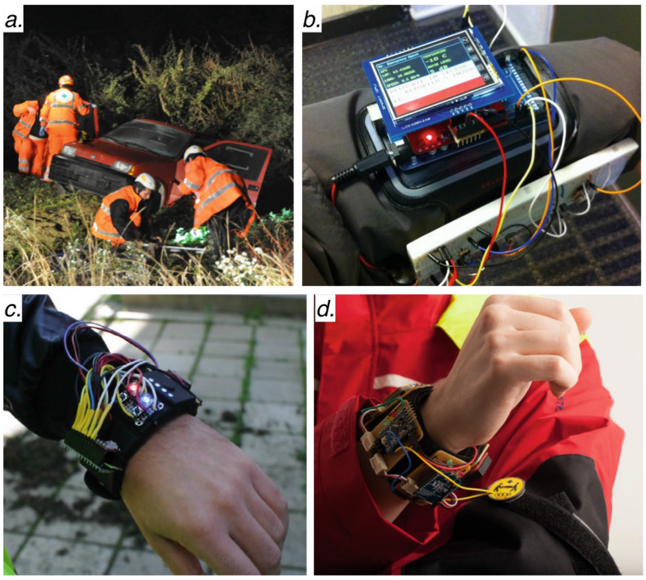

Fig. 1. Design iterations

Likewise what reported in the study by Kyng et al. [7], we observed that the system in place presents several pitfalls that makes difficult to maintain an overview of the incident site and to log operations. Information is distributed across people along the command chain and the coordination team easily fails in keeping track of information such as number of the rescued and injureds, or location of available resources; often requiring field agents to transmit twice the same information. This is worsened by the use of different radio systems among heterogeneous workgroups that cannot communicate with each other, requiring workers to use personal cellphones or have to find each other physically to coordinate [7].

This study allowed us to get familiar with the work setting and to identify main design challenges for devices suitable to be used during crises.

Building on our analysis and exploiting the Arduino[1] rapid prototyping platform, we developed our first prototype of wearable sensor for data capturing (Figure 1-b) [21] and we tested technology acceptance with experts. Results were encouraging and pushed us towards improving wearability and deepening our understanding of which types of information are relevant to be captured.

Based on the results, we created a second version of the prototype adopting a watch-like form factor (Figure 1-c). Furthermore in April 2012 we ran a second focus group with 10 emergency workers to evaluate the prototype, to investigate new interaction techniques and to refine scenarios of use. Workshop participants had different roles and different levels of experience.

Addressing the requirements for wearability, modularity and user control gathered over the first two iterations, we eventually designed the third and current version of WATCHiT (Figure 1-d). Our prototype, described in detail in section 5, is wearable and can be worn under the work uniform. It empowers emergency workers to capture information while being on a crisis scene and without interrupting the rescue work. Data captured by sensor modules might include both information from the individual (for example stress level, mood and personal notes) and information sensed from the environment (like temperature, gas or radioactive exhalations). Data captured, including an identifier of the transmitter, is wirelessly broadcasted to ZigBee-compatible[2] receivers, enabling data logging and integration with existing information systems.

In the rest of the paper, we build upon the three iterations to draft design challenges as suggestions for driving the development of wearable computers for supporting data capture in crisis management. Later on we describe how we implemented the challenges, formalized in system requirements, in our current prototype (Figure 1-d).

4 Design challenges and requirement analysis

Analyzing the data gathered during three user studies we were able to define the following challenges to drive the design of data capturing tools for crisis work.

DC1. Mobility of work and sensing - Due to the nature of crises, sensing information with static sensors embedded in the environment is not always a viable solution. While urban environments, especially big cities, are getting populated by many sensors, there are large areas of the world that are not instrumented, or not instru-

[1] Arduino – http://arduino.cc
[2] ZigBee protocol - http://www.zigbee.org/

mented with the right type of sensors. It is therefore important to complement data from static sensors with mobile ones. The degree of mobility is also important. While rescue vehicles can be equipped with sensors, the highest degree of mobility is achieved with sensors worn by the workers. Indeed, rescue protocols require vehicles to be operated in areas that are already secured, while walking units are first to explore undisclosed environments.

DC2. Different crises, different relevant data – Experts stressed that being each crisis almost unique, it is difficult to define which data might be relevant based on generic typologies of crises. One kind of information acquired on the field that might be relevant for a crisis could be useless for another kind of emergency. For example a Geiger counter sensor provide relevant information during a nuclear plan accident, but it is nearly useless information during other type of accidents. Moreover data is also depending on the role of the worker.

DC3. Different types of data - Three classes of information have emerged from our studies:

a) Information for assessment of the worker's safety and wellbeing (e.g. stress level)
b) Information for mapping the territory and the work (location, temperature, humidity, etc..)
c) Information related to the rescued people (e.g. pathology, protocols actuated, medical supplies used).

In the current practice, some information is collected in writing using coded language; some is not collected at all.

DC4. Sensor data and user-submitted data – Some data (e.g. quality of air) is quantitative in nature and can be collected with dedicated sensors, possibly through highly standardized protocols. Workers might however provide critical qualitative data that cannot be measured with sensors, for example the perceived level of panic in an area. Data from different sources, sensors and humans, might help in building a more complete perspective.

DC5. Different use, different sharing - Some types of information can be very useful for real-time coordination of different forces. For example it is important that the first responders map the territory including safe and dangerous zones for the next rescue units to come, experts say. Therefore those data should be shared among co-workers in real time. Instead, information relevant for self-assessment of the worker conditions (e.g. stress-levels, engagement, ..) are core information for personal reflection that often can't or don't want to be transmitted real time during the emergency, or to be reported in formal documentation. Those are sensible data that the owner could choose or not choose to share with colleagues and supervisors. If shared those data could also help to activate an after-work psychological support for the worker.

DC6. Intuitive, hands-free interaction - Experts drew attention on the need for simple and intuitive user interaction approaches that leaves hands free for the work. The focus of the workers must be as much as possible on the rescue operation and not on data capturing and logging, they say. Most of the tasks a field worker is engaged in require both hands to be free; for example to carry someone on a stretcher, to break into a building or to set up a field hospital as quick as possible. (*"Forearms and* *hands are needed to be free for movements and to raise weights"* experts say). It is also considered unfeasible to use consumer technology like smartphones because it's nearly impossible to use touchscreens with gloves and the use of a smartphones at work could be misinterpreted in some cultural settings. Because of the harsh working environment audio and visual feedbacks could be problematic but also haptic feedbacks could not be a proper choice because the thick jacket worn by the workers would soften the vibration feedback; unless the device is worn underneath the uniform.

DC7. Automate and discrete capturing - There are two different approaches to data capturing: automatic capturing and discrete capturing. During automatic capturing sensors systems continuously monitor and capture information. Examples of these sensors can be a GPS that track the path of the worker and a chest band that sense heart pulse. That information must be analyzed either by human or computers to extract peaks and connect the raw data to context information needed to link to work episodes. During discrete capturing the system doesn't automatically capture information and it's up to the user to trigger the capture of precise information at a precise time/location, via a user interface. In this case the information captured is highly contextualized. On the other side field rescue work needs a user interface suitable to be used on the field and compatibly with rescue protocols.

The identified challenges have been formalized in three core requirements to the supporting technology:

Wearability, to address Design Challenges 1,3

Wearability impacts on form-factors and raw material for building the device. The design space of wearables for emergency workers is very narrow. For example working uniforms are highly standardized in protocols that strictly limit the areas of the body a device can be worn on. Pockets are assigned to specific tools or part of the body must be left free for operating tools. The technology might also limit the wearability; for example an hear-pulse sensor device must be worn on-skin and underneath clothes, while environmental sensors have to be worn on top of clothes in direct contact to the harsh environment typical of crisis (high temperature or humidity, for example). Wearables for crisis must be small and light enough to not hamper or distract from work duties but at the same time resilient to endure simulated rescue operations. In fact, although prototypes are not meant to be used during real-life operations, simulated exercises are set up to resemble real emergency; including the continue exposure of workers to fire, water and extreme temperatures.

Modularity, to address Design Challenges 2,3,7

Modularity deeply impacts on hardware and software architecture design. Modularity in system architecture is required to make wearables that are customizable to specific contexts of use and user groups. Crises present very varying peculiarity. Although classifications of crises both for severity and typology are available each crisis is nearly unique and it is likely to not be replicated in the future. Capturing the relevant information is critical, yet it is difficult to foresee the type of data and context information that is relevant to be captured. Building a wearable device that embed every sensor for the data relevant for any crisis would make the device too big and power-consuming to be wearable. Modularity can address the need for capturing the relevant data by allowing a generic wearable device to be customized with sensor modules relevant before a specific crisis.

Distraction-free User Interaction, to address Design Challenges 4,5,6

Distraction-free interaction impacts on hardware, software and wearability. Once more, the specific domain narrows down the design space of wearables, this time in terms of user interface. For example the use of touch-screen interfaces is not doable to workers wearing heavy gloves. The user interface paradigm for WATCHiT need to disrupt as little as possible the user's concentration and hands, to not interfere with rescue protocols and the current use of existing tools.

5 WATCHiT Design

Leveraging rapid prototyping techniques we designed a WATCHiT prototype which addresses the identified requirements. The prototype is fully functional and it has been evaluated during training events.

WATCHiT is a wearable computer sewn in a wristband to be worn under the work uniform (Figure 2). It allows emergency workers to capture information while being on a crisis scene and without interrupting the rescue work. Data captured might include both information from the individual, for example stress level, mood and personal notes; and information sensed from the environment like temperature, gas or radioactive exhalations.

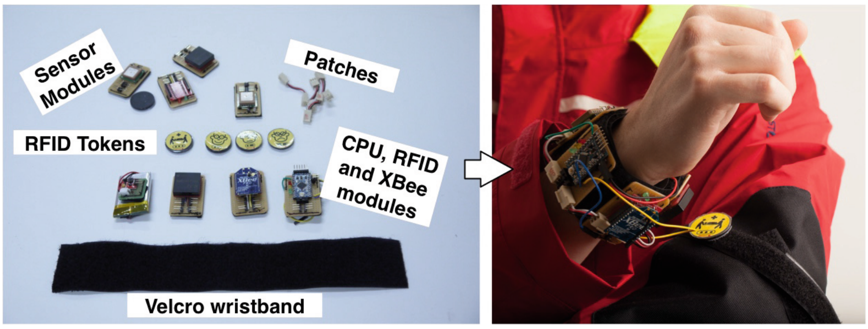

Fig. 2. WATCHiT parts

WATCHiT doesn't constitute an application itself, like any input devices it has to be considered as a user interface to specific application logics, simple template code for system integration and APIs are available at [22].

WATCHiT makes use of physical *sensor modules* for transient customization of the device functionalities, and RFID tokens to implement a *distraction-free* user interface for tagging data captured with useful context information. A Velcro wristband is used as mounting platform for the modules (Figure 2) and 3D-printable hard shells protect the device when in use.

5.1 Modularity

We designed a completely modular device. Our architecture allows experts to customize the device to address the need for capturing data in specific emergencies and for different user groups. It also introduces opportunities for designers to build applications that are not limited by a pre-defined hardware: each application can be designed to work with a specific set of modules or to provide extended functionalities when additional modules are available. On top of that a modular design allows new functionalities and sensors to be introduced into the system in the future.

WATCHiT modules fall in three categories:

Core – are mandatory modules for the device to work. They provide CPU, battery and RFID capabilities. A CPU module includes a microprocessor, memory, I/O connectors, status LEDs and a tiny vibration motor to provide haptic feedbacks. The battery module powers up all modules daisy chained with 3-wires patches and include a rechargeable battery and mini-USB connector for charging. The RFID module allows the wristband to read textual labels encoded in passive tokens when the wristband is hovered onto them (at a distance of 0-3cm). The RFID is needed to implement the body shortcut interaction technique described in the next sub-section.

Sensor – are modules that embed sensors for specific data types. These modules can either capture environmental data (e.g. hazardous gas, temperature) or vital signs from the wearer (e.g. heart-rate, blood oxygenation). They are built using standard sensor parts and provide a 1-wire interface to the CPU module to exchange sensor reading. Compared to traditional handled sensors they hinder application developers from dealing with multiple data-exchange formats, thanks to the WATCHiT API. From a technical point of view, sensor modules optimize resources (one shared CPU and power source), allowing the construction of smaller and cheaper devices. At the present time we have prototyped modules for sensing time, location (GPS), temperature, noise and heart rate.

Broadcaster – enable sharing of data using wireless protocols. At least one broadcaster is required to connect WATCHiT to a device running an application layer. We have prototype a *broadcaster* for the Xbee Pro standards. The Xbee pro standard can share data with receivers in a range of 2Km, allowing multiple WATCHiTs to interact with a centralized system, e.g. for logging data.

While modules are daisy-chained to share the power source, each module requires an additional 1-wire connection to the CPU for data exchange, limiting the number of module simultaneously connected to 7. This is a limitation of the current prototype that will be addressed in future design iterations.

5.2 Distraction-free user interaction via RFID tokens

WATCHiT's RFID tokens empower users to (i) activate specific sensors, (ii) tag the collected information with user-generated information.

Tagging sensor raw data with human-readable information has multiple benefits: (i) can describe a context for a data-point helping making sense processes, especially when a piece of information is reviewed later in time (ii) can classify data captured discerning between relevant data and noise, (iii) can be used to set a level of privacy for the information captured.

In our prototype we experimented tagging sensor data with text messages reporting on workers' stress levels and activities on the field; this information can be useful to support debriefings and reflection. For example a worker can tag location data captured with the GPS sensor module with text messages about her actions and behavious like "Here I rescued a person" or "Here I don't feel confortable with this situation". With tags we also address the need for capturing both quantitative and qualitative data.

Introducing tags required to design a user interface for tagging, in real time and without interrupting the work, the information acquired by sensors. Designing a user interface to interact with WATCHiT we built on prior works on mnemonical body shortcuts [23, 24], and body-centric interaction [13].

In [24] Guerreiro et al. propose the use of body locations as a placeholders to trigger pre-defined, programmable digital operations to be a more intuitive alternative to voice or key shortcuts in mobile contexts. Such digital operations are triggered by temporary holding a smartphone on pre-defined body areas. For example, holding the phone on the wrist can set an alarm on your Google calendar; while holding the device on the mouth could initiate a phone call. Chen et al. [13] further included body shortcuts techniques in the broader class of *Body-Centric Interaction with Mobile Devices*, highlighting that people can apply their associative experience to semantically relate their body parts to certain digital actions. Furthermore the kinesthetic sense [25] would allow a person to reach the body parts with reduced visual attention.

WATCHiT leverages mnemonic body shortcuts for tagging raw sensor data with a set of pre-defined textual labels encoded in RFID tokens; and we extend the use of body shortcuts to also include interactions with objects. Yet, instead of holding a phone on body locations, the user holds the wrist wearing WATCHiT on areas marked by RFID tokens. The WATCHiT wristband embeds an RFID reader (as *core* module) to read the textual labels and append them to the raw data samples that are being sensed. Raw data and textual labels are eventually broadcasted. In this way we aim at providing an interface that is less disruptive for the work compared to handheld devices currently in use, voice or touch-based interaction.

The semantic of textual data written onto RFID tokens can be set to address the need of tracking a specific work practice or the role, or even to control or pause data acquisition. Developers can therefore easily create new tokens driven by a specific application logic or visualization. A typical customization procedure for WATCHiT is the following.

Tokens are configured by adding textual contents using RFID transceivers ot enabled smartphones, and get visually labeled with mnemonic aid (Figure 3-a). Then tokens are appended on parts of working uniform or tools used on action (Figure 3-b), leveraging associative users' experience to create mappings that are easy to execute, understand and remember [13]. For example by sticking an RFID token encoding the label "Injured rescued" on a stretcher a worker could easily tag locations of rescue operations with a quick interactions that might become part of her work routine. Eventually, once a token is read by hovering WATCHiT (Figure 3-c) raw data being captured gets tagged with the textual label encoded in the token (Figure 3-d). The richer information is finally send (thru *broadcaster* modules*)* to receivers the users is acknowledged by haptic feedbacks on the wrist. Receivers use the data to trigger digital operations or change in visualization according to specific application logics.

Fig.3. WATCHiT user interface

5.3 Scenario of use

In the following we describe a possible scenario of use for WATCHiT from the point of view of a fictional character named Giacomo.

Background. Giacomo is a firefighter. One day, Giacomo's team is alerted for a wildfire in a nearby chemical plant, several people are reported to be missing.

Scene 1. While getting ready for the rescue mission Giacomo receives a WATCHiT configured with modules for sensing location, noise, temperature and a module for Xbee broadcasting to the control room the data he acquires.

Scene 2. Furthermore Giacomo receives from his team manager RFID tokens for tagging the location where a missing person is found and for tagging sensor data with a self-assessment of his stress level via three emoticons.

Scene 3. Giacomo wears WATCHiT on his right wrist and ties the tokens on his left arm using Velcro laces (Figure 3-b). He is now ready.

Scene 4. Giacomo breaks into a building on fire and rescue an injured person, he broadcasts the location and air quality measurement where he found a person by hovering WATCHiT on the relative token (Figure 3-c).

Scene 5. When a token is read, a sensor reading is acquired, tagged with the information embedded in the token, eventually broadcasted or stored in the device according with privacy setting.

Scene 6. After a token is read, and the data broadcasted to the coordination room, Giacomo is acknowledged by a haptic feedback on the wrist.

Scene 7. Thanks to the information collected and sent in by Giacomo through WATCHiT, the coordinator knows that it is safe to send in more units.

Scene 8. Later on Giacomo feels he cannot hold up anymore to his task. He tags data captured when he's checking out from duty with a "high stress-level" tag. He will later analyze data captured during the mission to reflect on his experience.

6 Implementation

The final prototype of WATCHiT has been developed around a core module which hosts Arduino Pro Mini board [26]. The core module also embeds a backup memory for the information captured. Default modules includes:

- Power module which includes a 800mAh battery to guarantee a 4-hours autonomy during normal operations
- Broadcaster module based on a Xbee S1 PRO chipset, which guarantees communication within a 1.5Km range in open air.
- RFID tags can be read thanks to a module which embeds an ID Innovations ID-12 chipset for scanning of 125KhZ RFID tags within a 10cm range.

The set of sensor modules prototyped so far include a location module built with a Fastrax UP501 GPS chipset and a hearth-pulse sensor built with the pulsesensor.com finger worn sensor. WATCHiT runs a firmware developed with the Arduino IDE. The code is available under an open source license at [22]. WATCHiT broadcasts data in a simple JSON format and it can be programmed leveraging the Arduino IDE to address specific application needs. Template code is provided at [22].

Shells to protect modules during user evaluation have been designed 3D printed. The total cost for the components is about 250 USD.

7 Evaluation

The evaluation of our final prototype took place during a two days training event for field rescue operations. Classroom teaching of rescue practices was complemented by simulated rescue missions in a city park setting where inexperienced rescue workers were shadowed by disaster managers. Each mission consisted in finding a dummy hidden in the grass, simulating a BLS (Basic Life Support) practice directly on place (Figure 4), under the supervision of experts, and finally carrying the dummy to an ambulance using a stretcher.

Fig. 4. Emergency workers during training

Two rescue workers took part to the evaluation of WATCHiT: a young inexperienced field rescuer and an experienced team coordinator. One of the two participants also took part in a previous evaluation of the system. Two WATCHiT were set up with a module for location sensing and four tokens for the sensor were customized with the tag-messages "Found a person", and the description of moods: "Happy", "So and so", "Sad". The two agents were asked to wear WATCHiT and append the tokens on the uniform where they find less intrusive. They were asked to use the system to report the location where they find the dummy to be rescued and use the moods tokens to give an assessment of their performances at each step of the BLS procedure; which is activated after the discovery of a injured. The simulation was recorded using a head-mounted camera and the video footage was later analyzed. The goal was to understand whether the WATCHiT prototype and the token-driven interaction it features can be successfully used during a rescue operation (although simulated) and find suggestion for improvement of the system.

Results from the video analysis and a post-simulation meeting with the users show that the interaction technique based on mnemonic body shortcuts was well accepted. The workers could easily fit WATCHiT underneath the heavy work uniform and they appreciated the distraction-free interaction and the freedom of movement.

We validated that body gestures (e.g. shaking or crossing arms), which leave hands free as much as possible, are a suitable approach for the interaction with the device, to trigger the capture of a particular data without interrupting the work. Tokens can be worn on the work uniform using bands and Velcro (work uniforms observed in action already used Velcro bands for attaching labels like the name and field role).

Participants also reported to have clearly perceived all the tactile feedback patterns on the wrist.

On the other side WATCHiT and its modules are too fragile to be used during a simulation and consequently during a real emergency. The perceived fragility of the devices made them keep focus on protecting the device from shocks and contributed to distract the workers from the action. Indeed one of the two WATCHiT got partially damaged during the experiment.

An interesting behavior was observed, the experienced worker used the mood-tokens to evaluate and rate the work of the young worker rather than to give an assessment of his own stress level. Although it is complicated to understand whether that behavior was due to the training purpose of the simulation and would not be observed during a real crisis, this can be seen as a tentative to hack the system being WATCHiT used to collect information about another individual rather than oneself or the environment.

Since the first design iteration, experts said that WATCHiT could play an important role especially in the early stages of an emergency where the first responders need to map the territory for the other units to come and coordinate the rescue operations. In this agitated phase there's often a lack of coordination among the different forces in stake and WATCHiT could fill the gap by facilitating sharing of data intra and inter different teams. Moreover information collected could help in the debriefing phase of the emergency and the information could be used in case studies during training of new personnel, experts say. Currently, data sharing with colleagues is handled by vocal communication over analog radio devices. Experts believe that while radio communication should still be used as the main cooperation tool towards implementing rescue protocols, some information could be collected and shared by WATCHiT, to avoid overloading radio operators.

8 Conclusion and future works

Through an iterative design process that has involved target users from the very beginning, we created a modular wearable tool for situated data capturing of quantitative and qualitative data on a crisis scene. We designed for our tool a hands-free user interface which exploits tokens attached to the worker's body and tools. We validated that our interaction technique is compatible with emergency work and the captured information can assist the phases of coordination and debriefing in crisis response.

Future work is planned in four main directions. First, we plan to generalize the interaction model to support more complex interactions, e.g. controlling the degree of sharing. This will include a study to clarify sustainable complexity. Second, we want to investigate different forms of wearability, for example integrating the modules into rescuers' jackets, in line with initial work presented in [21]. Third, we plan to develop a tool to support users in the definition of their own tokens, supporting better the "hacking" processes that we observed in the field. Finally, we plan to make WATCHiT available for long-term use to investigate how it integrates into rescue practices.

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Paper 4

Don't Panic: Enhancing Soft Skills for Civil Protection Workers

Ines Di Loreto, Simone Mora, and Monica Divitini

In Proceedings of International Conference on Serious Games Development Applications (SGDA)

Is not included due to copyright

Paper 5

The interactive-token approach to board games

Simone Mora, Ines Di Loreto and Monica Divitini

Ready for submission

The interactive-token approach to board games

Omitted for anonymity

ABSTRACT. Recent advances in interactive surfaces and Tangible User Interfaces have created a new interest in digital board games, aiming at mixing the benefits of traditional board games with the interactivity of video games. Within this strand of research we propose a new approach centered on the concepts of tokens, constraints, spatial expressions and interaction events. While mainstream solutions implement game interaction using interactive surfaces, our approach relies on physical manipulation of interactive objects on conventional surfaces. We illustrate the proposed approach by describing the design and development of a game for training of emergency workers. Building on feedbacks from user evaluation and our experience with the development, we outline design opportunities and challenges of the approach.

Keywords. Tangible User Interface, digital board game, interactive objects

1 INTRODUCTION

Playing board games is an engaging social experience characterized by two levels of interaction: between the players themselves (e.g. discussing strategies), and mediated by physical artifacts representing information and actions (roll a dice, draw a card). Such rich experience is facilitated by the social and physical affordances of the principal elements in common to any board game: board and game pieces. While sitting around a board affords for face-to-face and gestural communication and cooperation, game pieces allow for tangible interaction and physical feedbacks.

Starting from the 80s, computer version of popular board games came to the market, like *Chess* and *Risk* for the commodore and Atari platforms, offering a full virtualization of board and game pieces. Keyboard and point-and-click interaction replaced physical actions around the board. Even if some of these games also offered a multi-player mode, this did not facilitate face-to-face interaction (rather a shoulder-to-shoulder interaction) [1] and simultaneous actions. With the evolution of computers fully virtualized digital board games gained higher-definition graphic and sound. Still, the lack of tangible interactions impacts on the game experience, because the manipulation of digital and physical media are fundamentally different [2] and the social experience is different as a computer or the console are acting as a mediator [3].

Taking advantage of advances in interactive surfaces and Tangible User Interfaces (TUIs), several works aim at introducing interactivity in board games, yet preserving their traditional social and physical affordances, by replacing the game cardboard with a touchscreen computer (e.g. iPad, tabletops). The screen becomes an interactive board capable of graphical and auditory stimuli and reacting to touch-inputs and manipulation of objects tagged with fiducial markers. Although this approach has become mainstream, it confines interactivity to a touchscreen area, posing a tradeoff between span of the touchscreen surface (and thus the interactive space) and costs.

In this paper we introduce a novel approach to the digitalization of board games inspired by the Token+Constraint paradigm [4]. Rather than focusing on interactive surfaces, we focus on transforming game pieces into interactive tokens, preserving the board as passive element. The actions players can perform on game pieces are then defined by the physical and visual constraints provided by the board and game rules, as it is with traditional board games.

In order to prove its validity, we applied our approach to the augmentation of *Don't Panic* (DP), an existing board game to train emergency workers on panic management. Starting from its cardboard prototype, we re-designed *Don't Panic* around interactive tokens and we built a working prototype leveraging digital manufacturing techniques. It is important to stress that the focus of this paper is not on the game itself, that it is only used for illustrating and validating the approach. The interested readers can find the description of the game and its evaluation in [5] (cardboard version) and in [6] (mobile version). This game was chosen because it implements elements that are generic to board games, like *pawns* and *cards*, and it has a complex but limited set of functionalities to illustrate our approach in a concise way.

The paper is structured as follow. We first review the state of the art of current digital board games implemented with interactive surfaces. Our design approach is then presented and grounded in existing conceptual frameworks. Next we describe how we applied our approach to *Don't Panic*, we discuss the evaluation of the approach. Finally we draw lessons learnt in form of design opportunities and challenges.

2 STATE OF THE ART

In this section we present research on digital board games with elements of physical interaction. The works presented hereafter can be set in the broader field of pervasive gaming, which aims at bringing physical and social interactions back in computer games [7]. Within this research we identify two main themes: (i) stationary interactive surfaces, and (ii) mobile interactive surfaces.

2.1 Stationary interactive surfaces

Computer-augmented tabletops have recently been proposed as an ideal platform for digital board games development [8], able to mix some of the advantages of low-tech board games with the benefits of video games [9]. Indeed, sitting around a technology-augmented tabletop allow users to be closer to the digital information and at the same time it enhances collaboration and communication among the users [10], reintroducing the user experience of face-to-face gaming and simultaneous actions. Tabletops can be augmented with technology to play games using different flavours of augmented reality, as in [11, 12]. In particular, with the introduction of projectors and touchscreens, a number of works have used vision-based tabletop computers like DiamonTouch [13] and Reactable [14] as platforms for digital board games development. Several examples are available in the literature, including e.g. games to foster game-based learning [15] and entertainment [16]; for a review see [8]. Whilst the direct manipulation of virtual objects supported by vision-based systems and touch-screens makes these games more similar to analog board games, the resulting social experience is still different from the three-dimension sensory feedbacks experienced by playing with dices, pawns and cards. For example physical objects allow for peripheral interaction during the game and permit passive players (in turn-based games) to manipulate game pieces as long as they don't break the rules [17].

To address these limitations, game designers have started combining the touch-based interaction of tabletop computers with interactions through physical objects placed on the screen surface as means for controlling virtual game elements. In this way conventional objects can become game pieces (i.e. pawns, cards) by attaching active or passive tags recognizable by the tabletop computer. Several works have introduced physical objects in tabletop board games. For example in *Weathergods* [16] players uses different physical artifacts as players' avatars and to perform actions in the game. In *False Prophets* [18], *Knight Mage* [1] and the STARS edition of *Monopoly* [1] tangible objects act as characters in the game. In *IncrediTable* [19] players can modify the game board with smart-pens and combine physical and virtual objects to solve puzzles. In order to facilitate the implementation of tabletop-based tangible games toolkits are available, for example [20]

The two main drawbacks of tabletops computers are mobility (they are bulky and heavy) and costs, limiting their widespread used for gaming. Low-cost alternatives, e.g. [21], are under development, but not yet available outside research labs.

2.2 Mobile interactive surfaces

Considering the limitations of stationary interactive surfaces, a complementary strand of research has focused on the use of smaller but more affordable touch-screen devices, i.e. smartphones and tablets. Several technological solutions can be used to make the touchscreens of smartphones and tablets able to identify and track physical objects, for example using active [22] or passive [23] tags. Recently, various game companies have commercialized physical pawns for playing board games on tablet-PCs, e.g. *iPieces* [24] and *ePawns* [25]. These solutions attempt to recreate a tabletop-like setting using tablet-PC hardware, but the small screen (compared to a traditional paper board) can deteriorate the gaming experience due to information occlusion and overloading. A recent trend in game development for tablets tries to overcome these issues by exploiting the emerging research in Around-Device Interaction (ADI) [26] to expand the area of play outside the device's screen for example using magnetic accessories [27] or employing an hybrid, partially interactive board as in the Hasbro *zAPPed Monopoly* edition [28]. In this game, the original Monopoly board is augmented with digital contents produced by an iPad; some interactions are low-tech, e.g. moving the pawns on the board, some others are mediated by technology, e.g. buying a property. Notably, in this implementation the digital and physical representations of the state of the game are disconnected. Finally, *Disney Infinity* [29] and *Activision's*

Skylanders [30] make use of RFID-enabled platforms and collectible figurines to store players' profiles and un unlock videogame features.

3 The Interactive-Token approach to board games

As detailed in the state of the art the dominant paradigm for designing digital board games consists in adding active or passive objects on top of interactive surfaces. These objects complement and facilitate interaction with the interactive surface by offering affordances proper of the physical world for controlling virtual artefacts and controls (buttons, menus).

We propose a different approach: the game pieces are the means to bring interactivity and not the board per se. Distributing interactivity across multiple components opens for a wider space of possibility and a higher degree of flexibility in shaping the game experience. For example, game pieces can influence the state of a game not only when they sit on the interactive surface, but also when they are manipulated over and around it. In this way, the board is mainly used to stage the game and set a context for the use of the pieces, as in traditional board games. Also, in this way the interactive area of the board is less limited by size, which also determines the portability of the game (and costs).

3.1 Shifting perspective

Our investigation aims at augmenting the two intrinsic roles commonly found in board games: *control* and *representation.* For example: pawns serve as a visual representation of players, shared items (e.g. houses in Monopoly) as a representation of a resource count. The action of rolling a dice or drawing a card acts as a control for a (random) variable, allowing the game to evolve from a representational state to another. Each game piece can serve one role (as in Monopoly), or both (as in Chess). Pieces usually represent players and resources via iconic or symbolic artifacts; moreover the spatial configuration of game pieces on the board provides the players with a shared awareness of the state of the game.

In interactive-surface implementations of board games, technology is usually employed to virtualize pieces' representations by means of computer graphic and sound. The player's physical interactions with game pieces are often substituted with traditional GUI metaphors. For example, the actions of rolling a dice or drawing a card are implemented in touchscreen gestures like pushing a button or pinching a virtual dice.

In our approach the role of technology is twofold. On one side it brings interactivity by augmenting, not virtualizing, pieces' material representations; on the other side sensor technology is used to capture players' tangible interaction with control pieces aiming at preserving their traditional physical affordances. For example an accelerometer embedded in a dice can sense the result of a dice throw, and update a digital variable in a way that is transparent to the player.

Interactivity is provided as a consequence of players' interaction with control pieces and by game rules, e.g. by means of small LEDs or LCD displays embedded onto pieces to convey graphic and video contents, otherwise as auditory or haptic feedbacks. Game pieces might still preserve their traditional aspect, having a tangible representation that complements an intangible or ephemeral representation provided by technology. As matter of fact pieces in board games are used to convey both static and dynamic information: for example players' identity and role don't change throughout the game and are often represented by a set of distinguishing pawns (or tokens), while resources or score associated to each player vary and they are usually represented by a number of shared artifacts (e.g. houses and hotels in Monopoly). In our approach designers can define the trade off between the two representations as a balance by static information to be provided by the tangible representation and dynamic information provided by intangible ones. For example in a revisited version of Monopoly tokens might preserve their physical semblances to identify players but might embed an intangible representation of the number of property owned by the player (e.g. in digits, icons or symbols on a LCD display). The intangible representation is kept updated by a computer game engine during the playtime, as a consequence of players' interaction with control pieces and activation of game rules.

3.2 Architectural view of token-interactive board games

From an architectural point of view (Figure 1), a digital *model* of game variables and rules (stored in a computer game engine) mirrors the spatial configuration of physical game token on the board. Each token has a *tangible representation* (i.e. shape, color) that identifies the piece and defines its affordances; in addition it might have an *intangible representation* (graphic, auditory), controlled by the digital model, that is updated anytime the manipulation of a piece with control powers pushes a change in the model. The interaction with pieces is based on a double loop [31]. A first interaction loop consists in the passive haptic and visual feedback the player perceives when manipulating pieces on the board, this loop is in common with traditional board games. A second loop adds interactivity by means of graphical and auditory feedbacks conveyed via the tokens' intangible representation. This loop requires technology for sensing tokens' manipulations as well as providing visual/audio feedbacks (Figure 1).

Our approach is conservative towards traditional game mechanics. Technology is used for digitalizing and augmenting players' interactions with the pieces rather than reinventing them.

The set of valid interactions with game pieces are defined by the affordances of pieces and by game rules. To formalize these rules we build on two theories: the Token+Constrain framework [4], providing a powerful descriptive language, and the MCRit (Model-Control-Representation (intangible and tangible)) model [32], proposed by Ulmer and Ishii, addressing issues of representations and control in TUI.

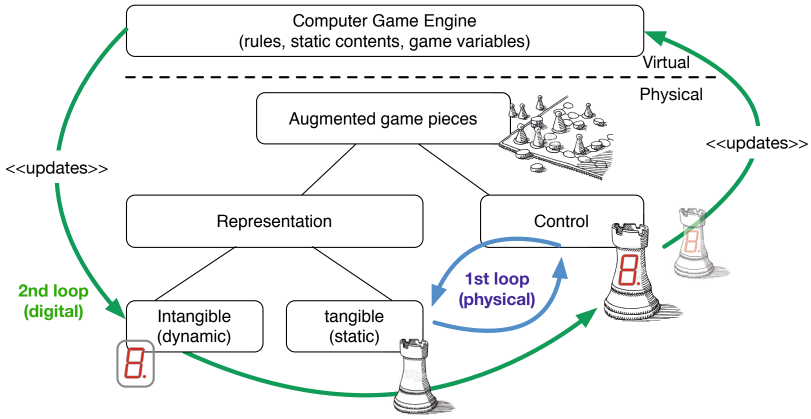

Fig. 1. Double interaction loop in interactive board games

3.3 Theory grounding

The Token+Constraint framework defined by Ullmer et al. [4] defines *Tokens* as discrete physical objects that represent digital information and Constraints as either mechanical or visual confining regions that are mapped to digital operations. By the interaction phases of association and manipulation of tokens within a system of constraints it is possible to map physical actions to a set of computational operations; for example the presence or absence of a token in a constrained area could be easily digitalized in binary information.

Besides the T+C paradigm focuses on the use of tokens and constraints as means to trigger digital operations, physical artefacts are also characterized by their physical appearance. Indeed, the "seamless integration of control and representation" [32] is a distinctive characteristic of TUIs over traditional GUIs, where control and representation are decoupled in input (e.g. keyboard, mouse) and output (e.g. screen, printer) devices. Aiming at going beyond the traditional MVC (Model-View-Controller) paradigm, in [32] Ulmer and Ishii propose an interaction model for TUIs called MCRit, Model-Control-Representation (intangible and tangible). They redefined the view concept of graphical interfaces as a balance between a physical (the token's shapes and affordances) and an intangible representation (e.g. computer graphics and sounds). This approach allows for blending the flexibility offered by graphical elements of GUIs with the natural manipulation offered by TUIs.

The presented interaction paradigms can be integrated to drive the design of digital board games. The Token+Constraint approach provides conceptual tools for building tangible user interfaces that leverage interaction with physical game pieces for controlling digital representation of game elements, hence preserving the affordances of board games. The MCRit paradigm allows for adding interactivity by augmenting, not replacing or virtualizing, the physical representation of game pieces with an intangible representation of digital information.

3.4 Key design constructs

Aiming at extending the T+C paradigm, we define a game, which is composed by *game dynamics* (the sum of game logic and rules)*,* as a sequence of player-initiated *interaction events* that modify *spatial configurations* of *tokens* with respect to board *constraints* and other tokens. Sequences of interaction events describe players' interaction during the game and allow a game to evolve thru states. In the following we describe how we extended T+C to address the design of interactive board games.

Tokens are technology-augmented artifacts capable of triggering digital operations that can activate game dynamics. Some tokens may be capable of sensing information (e.g. proximity with other tokens) and displaying computer graphic and sound (active tokens) or they can be conventional objects enhanced with electronic tags that act as triggers for game rules (passive tokens). Some tokens are personal, embodiment of the players on the board, while others are meant for shared use and can be handed around during the game. Tokens conceptualize all the tangible pieces traditionally used in board games. They range from the element of chance, e.g. a technology augmented dice in backgammon or RFID-enabled cards in monopoly; to game pieces, e.g. a pawns augmented with an LCD displaying the player's rank in the game.

Constraints are physical or visual confining regions in the board space. The association or dissociation of a token within a constraint can be mapped to digital operations to activate game dynamic. Moreover once a token is placed within a constraint the two can act as a system that enables nested interaction with other token-constraint systems. Constrained regions are determined by a perimeter that could be visual, or physical; the structure of the perimeter might permit a certain degree of freedom for the token (e.g. allowing for translation or rotation). Examples of constraints are checks for *Chess* pieces and territories in *Risk.*.

Spatial configurations are static relationships of *tokens* both with respect to *constraints* and to other tokens. They limit the space of interaction of players to a set of valid Token/Constraint and Token/Token relationship defined by a grammar of game-specific rules. For example, certain tokens can be associated only to selected constraints, relationship of proximity among tokens can be meaningful or not. Spatial configurations are used to validate players' interaction events with tokens against game rules, narrowing the set of interactions that are valid for activating game rules.

Interaction events are player-triggered manipulations of tokens, recognizable with sensor technology, that modify the (digital and physical) state of a game. We identified three types of events:

- *solo-token events (T)* - the manipulation of a single token over or on the board. For example the action of rolling a dice or drawing a card.
- *token-constraint events (T-C)* - the operation of building transient token-constraint associations by adding or removing tokens on particular planar constrained regions. For example adding a pawn to a determinate sector of the board. T-C events

can have different consequences depending on the game rules: in Risk, moving the armies pieces beyond a territory line is an attack action; in *Mancala* solitaire game the marble can only fit in an empty space and implies to eat another marble.
- *token-token (T-T) events,* the operation of building transient adjacency-relationships between tokens, achieved by moving tokens on the board. For example approaching a pawn next to another token artifact to unlock special powers or approaching two pawns to exchange a resource between two players. For example we can found T-T events as the action of creating a king in the Draughts game, which implies to put a game piece on the top of the other.

Sequence of interaction events sensed by technology, parsed and validated against spatial configuration by a game engine, can activate specific game dynamics, thus allowing the game to evolve from a state to another and triggering a change in intangible representation produced by active tokens. For example, we can model the act of capturing a piece in chess as a sequence of interaction events that modify proximity between two chess tokens within checkers constraints.

3.5 Design process

The design process of a token-based digital board game can be therefore summarized in the process of:

- Step 1: designing tokens, their tangible and intangible representations, and complementing board constraints
- Step 2: defining game-specific rules for building valid token-constraint, token-token relationships and interaction events.
- Step 3: mapping game dynamics to sequences of valid interaction events and defining changes of intangible representation.

In the following section we illustrate the design process by describing how it has been applied to the digitalization of an existing board game.

4 Applying the interactive-token approach

We applied our approach to the design of interactive tokens, board constraints and interaction events to augment a serious board game called Don't Panic (DP) [5]. The game shares similarity with many board games like the use of *pawns* to represent players, *items* to trigger game mechanics, and *cards* as elements of chance. This effort allowed us to evaluate the feasibility to implement game pieces as interactive tokens and map sequences of interaction events to preexisting game dynamics.

4.1 Don't Panic game dynamics and rules

Don't Panic, is a collaborative game inspired by Pandemic [33]. Four players start the game as member of a panic manager team that must work together to manage panicking crowds, in turn-based actions. A map representing a city map is displayed on the game board and the territory is divided in *sectors*. Each sector contains a number of people (PO) characterized by a panic level (PL). During the game panicking events (e.g. fires, explosions), randomly triggered by *card* drawing, increase PLs in determinate sectors. In addition, the panic increases at regular intervals. Each player is represented on the board space by a *pawn* and gets a limited number of actions with the goal to lower the panic level in the city. Using the “calm!” and “move!” tools a player can either reduce the panic in a specific sector or move panicked people to an adjacent sector (with lower PL). Information *cards* distributed in each turn can lower the panic in multiple sectors, for example the action “TV-broadcast” reduces the PL in all the sectors. The game ends in defeat for all the players if the entire map has panicked. Players collectively win the game when the PL in all sectors is zero. For a full description of game rules see [5].

4.2 Step 1: designing tokens, their tangible and intangible representations, and complementing board constraints

Don’t Panic is composed by a cardboard and a set of tokens. We designed both active and passive tokens; and both physical and visual board constraints. In the following we describe the objects and their meaning as game pieces.

The board (Figure 2-left) – is a cardboard that visualizes a map portraying a territory divided in nodes, sector and paths. Nodes are edges between sectors and are connected by paths, as in closed cyclic graphs. Nodes feature physical constraints and no degree of freedoms for the hosted tokens; sector and paths provide visual constraints allowing tokens’ translation and rotation, within the perimeter.

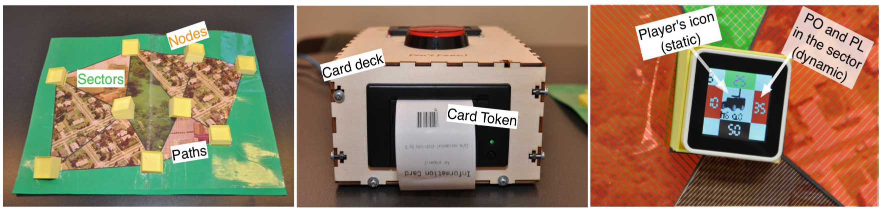

Fig. 2. Don´t Panic interactive tokens

The card deck (Figure 2-center) – is an active token to dynamically print information card tokens. Each card has a textual description of how it affects the game and a barcode that links the card to its digital representation. The top surface of the card deck can identify by proximity cards that have been previously produced and trigger actions in the game. Cards don’t affect game dynamics immediately after they are produced; they can be kept or exchanged by players, until when they are activated by proximity with the card deck, anytime during a game.

Pawns (Figure 2-right) – are active tokens that embody the players’ presence on a node, each player interact with a personal pawn during a game. Pawns can be dragged from node to node, as long as a path directly connects the two. Each pawn provides static and dynamic information via a LCD display. The static information shows icons linking to a specific player. The dynamic representation visualizes the number of people present in sectors adjacent to each of the four pawn's sides and their panic level (symbolized with colors). This information is contextually updated according with a pawn's location, since different nodes face different sectors. Besides their representational functions pawn also have a control role: in order to activate nested actions with other tokens the player has to reach the relevant node.

The Calm! tool (Figure 3-left) – is an active token that represent the action of going on the field and calming people talking to them, thus reducing the PL in a specific sector. The top display shows a numeric representation of how effective the action of calming people is, given the player's role in the active turn. When it is activated by proximity towards a pawn's side, it provides visual and auditory feedbacks.

The Move! tool (Figure 3-center) – is an active token that simulates moving people between sectors, in this way people moved acquire the panic level of the recipient sector. The top display shows the number of people that can be moved, given the player's role in the active turn. It also provides visual and auditory feedbacks.

Barriers (Figure 3-right) – are passive tokens that resemble iconic artifacts. Barriers avoid panic spreading and people movements between two adjacent sectors by physically inhibiting the action of the Move! tool.

Fig. 3. Valid interaction events

4.3 Step 2: defining game-specific rules for building valid token-constraint and token-token relationship and interaction events

After designing tokens and constraints, we defined valid token-constraint and token-token configurations and interaction events (Table 1). Token-constraint relationships are defined by univocal, transient associations created by the add/remove interaction event. Token-token relationships are defined by adjacency achieved via the move interaction event. The types of constraint limit the interaction events that tokens can afford. For example, physically confined tokens can only afford the *add/remove* (association with constraint) event, while visually constrained ones leave the player free to manipulate the token, e.g., to build proximity relationships with other tokens.

Table 1. Valid spatial configurations and interaction events

Token	**Associated Constraint**	**Interaction events**	**Tokens relationships**
Pawns	Nodes (physical)	Add, Remove	Adjacency to tools and barriers
Calm!&Move! tools	Sectors (visual)	Add, Remove, Move	Adjacency to pawns
Barriers	Paths (visual)	Add, Remove, Move	Adjacency to pawns
Cards	Card Deck (visual)	Move	Adjacency to the card deck

4.4 Step 3: Mapping interaction events to game dynamics

Table 2 presents the mapping between game dynamics and valid sequences of interactions implementing specific dynamics. Each sequence of interaction events result in a new physical configuration of tokens on board, in an update of the digital representation of tokens in the game engine, and it produces a change in tokens' intangible representations (graphic and audio).

Table 2. Mapping game dynamics to Interaction Events

Game Dynamic	**Interaction events (Type)**	**Changes in representation**
Move from node A to node B	1-Remove the pawn from node A (T-C) 2-Add the pawn to node B (T-C)	Panic and people display updated
Calm down people in a sector A (Figure 3-left)	1-Add the Calm! tool to sector A (T-C) 2-Move the Calm! tool towards a pawn's side facing sector A (T-T)	Panic display updated, auditory feedback
Move people between sectors A and B (Figure 3-center)	1-Add the Move! tool to sector A (T-C) 2-Move the Move! tool towards the pawn's side facing the sector A (T-T) 3-Add the Move! tool to a sector B (T-C) 4-Move the Move! Tool towards the pawn's side facing sector B (T-T)	People display updated, auditory feedback
Calm down people in multiple sector	1-Approach a card towards the card deck top surface (T-T)	Panic displays updated, auditory feedback
Create a barrier between sectors A and B (Figure 3-right)	1-Add a barrier to the path crossing sectors A and B (T-C)	Auditory feedback

5 Technologies and tools for implementation

Don't Panic has been implemented in a fully functional prototype. We designed the hardware and the software with the help of several commercial and open source popular toolkits. The system we implemented, a loosely coupled modular architecture, is composed by a game engine and a set of token handlers. The game engine implements game rules and stores a digital representation of game variables (e.g. PO and PL levels); token handlers bridge players' physical interaction with game pieces with their digital representations. Modules exchange information over a event-based messaging system over the socketIO protocol. As an example, when the player associates a pawn to a node, the relative location of the node to the board surface is acquired by sensors on the pawn, encoded in a JSON message and sent to the game engine. The engine updates the digital representation of the game state and messages back the pawn the list of sector adjacent to the node and relative PO and PL variables; the pawn uses the data to update information on the LCD display (Figure 2-right).

5.1 The game engine

The game engine has been implemented in javascript using the node.js framework. Besides activating game rules the game engine also acts as a server for handling communications with token handlers; moreover it exposes an HTML-based interface for remotely administrating game sessions and customizing game rules. The game engine runs on a raspberry pi, which is configured as WiFi hotspot to handle TCP/IP connections with TUI clients and with remote clients for game administration. The game engine also produces auditory feedbacks and music.

5.2 Tokens handlers

Pawns, Calm! and Move! tools have been implemented using the 1st generation of the Sifteo cubes [34]. Each cube is capable of sensing accelerations, proximity with other cubes on any of its four sides, and to display graphics on the top surface. The cubes' behavior is wirelessly controlled. Besides Sifteos are designed to implement games relying on physical interaction with interactive objects they didn't provide any specific developer tool to be employed as interactive pawns; for example APIs for sensing cubes' location relative to visual constrains on a 2D board space. In order to make the cubes recognize discrete locations on a board (required to used to cubes as pawns reacting to nodes constraints) we exploited in an unconventional way the data from the 3-axis accelerometer embedded in each cube. We designed sockets for the cubes each of them featuring a combination of unique horizontal tilt angles over two axes; the aggregated value of tilts angles is used as a fingerprint for the socket. We 3D-printed and embedded the sockets into the board as nodes constraints (Figure 2-left) and we coded the relation between sockets fingerprints and nodes' location. In this way when a player associates a pawn to a socket, the cube senses the surface tilt over 2 axes using the accelerometer, the aggregated valued is matched against socket fingerprints and thus the position of the pawn on the board is updated in in the game engine. As a current limitation, after each interaction with a cube the player has to push the upper side of the cube to confirm the action.

The card deck is crafted in form of a wooden box that encloses a thermal printer, a CCD barcode scanner and a raspberry pi (which also runs the game engine). The card deck allows for printing and recognizing cards during a game. A card manager module developed in Python allows for information exchange with the game engine. Although both game engine and card manager are deployed to the same hardware (raspberry pi) they are loosely coupled, allowing flexibility for future development. Each printed card displays text, graphic and a distinct barcode that is used to link the physical card to its intangible representation stored in the game engine. When the action of drawing of a random card is activated by a game rule, the game engine notifies the card handler to print text and a unique barcode onto the card. When a player plays a card by waving it towards the barcode reader, the engine is notified and it triggers an update in the set of variables and thus in the representation of panic levels on the pawns' display. The card deck area also features a push button and a LCD display, in the current implementation these devices are used to pass the turn and to display status information.

Finally, barriers are 3D-printed objects. As a limitation of the current implementation the objects cannot sense and notify the game engine about their location on board: the presence of a barrier on the board provides a physical, but not digital, lock between two sectors.

6 EVALUATION

The *Don´t Panic* prototype (Figure 4) was tested with 16 players aged 20-59, 6 were female. The goal was to explore (i) how the traditional social affordances of board games are preserved; (ii) how players understand tokens interactivity; and (iii) to reflect on design opportunities and challenges presented by our approach. The evaluation of *Don´t Panic* game dynamics is beyond the scope of this paper.

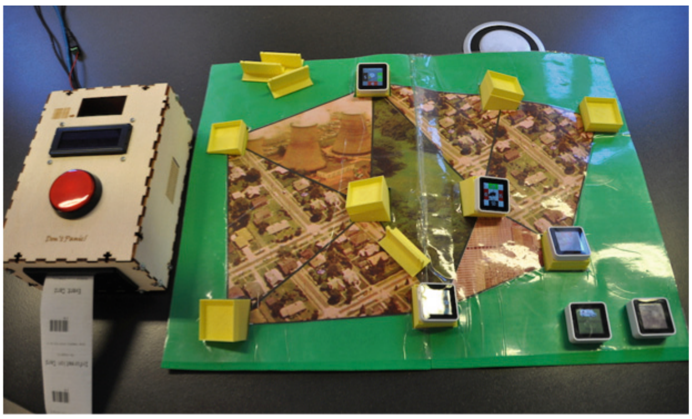

Fig. 4: The *Don't Panic* prototype tested during evaluations

Each evaluation session was composed by 4 participants in a controlled environment. After a game walkthrough, players were asked to play for 30 minutes, then to fill in usability (SEQ) questionnaires. In addition, sessions were observed and video recorded. Participants were aware of both, recording and the presence of the observers. A qualitative and quantitative analysis was done by two researchers on the collected data (2-hours video footage and questionnaires) following [35]. Selected sequences from the videos were used for closer inspection. In particular the researchers analyzed: *breakdowns* (e.g., interruptions in the process play caused by the technology), *physical manipulations of the tokens, focus shifts* and *strategy discussions*.

Utterances analysis shows that 65% of statements concerned *game strategies*. Only 18% (most of them in the firsts minutes of the game) concerned game management tasks (e.g. rules), demonstrating a steep learning curve. This result might be explained by the role of technology as a facilitator for rule retention. The remaining 17% of utterances concerned the use of token interfaces, often about usability issues (*breakdowns*), also noticed by the observers. Some group used a lot of verbal interaction (202 in 30 min) while others kept verbal utterances very low (52 in 30 min). Verbal exchanges were equally distributed among players.

Regarding *physical manipulations of tokens*, the usability of the system was rated very high (M=4, SD=0.9 in a 5-steps likert scale) by the under 40, and 3 (SD=1.5) by older players. Despite these results we observed some usability issues. Metaphors used for representing panic levels and people per sector variables were difficult to learn. Moreover several players had problems in reading and manipulating tokens when associated to nodes characterized by high tilt angles. Most of the *focus shifts* and talking about issues with technology concerned those aspects.

The interactivity brought by technology was highly appreciated by the players (M=4, SD=0.8). When asked about how interactive tokens fostered gameplay, players answered that they were helpful as (i) memory helpers "*[tokens' LCD display] let rules be clearer and there is no need to remember them*", (ii) facilitators for social interaction "*[tokens] add more interaction with people and make it easier to remember actions*". Moreover, the 87% of the players agreed that the usage of the objects made the game engaging.

Finally, when asked (open question) to compare *Don´t Panic* with respect to a traditional board game experience players considered it as "*less repetitive, quicker, more reactive*"; amusing and more interesting because of the interactive tokens: "*...[Interactive] objects add to the realism of the game*".

7 DISCUSSION

Through our research we aim at adding interactivity to digital board games preserving their traditional social and physical affordances. Pushing interactivity into tokens, letting the game board be a passive component used only to set physical and visual constraints, we are aiming at an approach that is an alternative to current mainstream approaches focused on the use of an interactive surface. In this section we reflect on our experience.

7.1 Feasibility of the approach

Our approach allowed us to design and implement Don't Panic in a fully functional prototype. We designed the hardware and the software with the help of several commercial and open source toolkits and we believe that the technology and tools employed can be re-used for the implementation of other games. For example we crafted the physical shape of game pieces with corn-based plastic and wood, using 3D printing and laser cutting techniques. We tinkered with the Sifteo platform [34] to extend its functionalities and integration with third-party technologies. From an architectural point of view, the separation between the game engine and token handlers has the potential to allow playing different games with the same set of interactive game pieces. It also allows for improving or experimenting with new user interfaces and interactive objects without altering the game engine implementation.

For what concerns the social dynamics, our evaluation highlights that the introduction of technology didn't alter the traditional social affordances of board games. Even if the interactive tokens were richer in terms of actions and feedbacks than traditional game pieces, this choice didn't disrupt the flow of actions in the game. Regarding physical interaction, game dynamics were successful implemented through sequences of interaction events. The learning curve was very low for most of the players due to the interactive tokens acting as memory helpers for the game dynamics.

7.2 Design opportunities and challenges

Blending strengths from the physical and digital domains. The blend of elements taken from the digital and analog worlds introduced new design opportunities that, in our experience, resulted in added interactivity and fun for the players. For example by adopting a card printer, we were able to mix the powers from the digital domain, to sort and select a huge number of choices, yet preserving the physicality of tangible interactions with cards, their flexibility of manipulation and extended visibility. We observed that game cards printed "on the fly" brought elements of excitement and surprise due to the players hanging on while a card gets (slowly) printed. Furthermore information on card can be designed to be highly contextual with the status of the game, or random, or tailored to role of active player or the level in the game. The physicality of cards also allows for playful interaction not conventionally available in traditional board gaming: card can be annotated, kept by the players for future reference or tossed.

Unconstrained interactivity. Besides analog affordances of board gaming, in our approach videogames interactivity (e.g. 3D-graphic, audio), useful to convey rich information and creating ambiance, can be still exploited by designers to a certain degree. Interactivity, rather than being confined in a single surface, becomes mobile being distributed across ecology of tokens. This opens for two new design opportunities. First, the role of computer graphic provided by tokens (for example via small embedded LCDs) can serve both as a private and public display. For example a token can provide secret information when is sheltered in a player's hand, yet becoming a display of public information when it sits on a board constraint. Tokens can be scattered around the board to project dynamic information over static regions of space; also they can be leaned side by side for extending display surface. This opportunity could be further exploited for designing games that make use of single-player interaction with tokens when they are off the board, and multiplayer interaction once they are back within board edges. Second, our approach poses little requirements to the design of the game board: only the definition of visual or physical constraints. This is a useful opportunity to implement games requiring a modular or incremental board, as new elements can be implemented quickly and inexpensively.

Balancing tangible and intangible representations. The design of tangible and intangible representations is critical to avoid usability issues. For example, in *Don´t Panic* a single token (Figure 1-left) captures information about the player (role and number of actions left) and information about the state of the game (distribution of people and panic levels). Although providing a quick awareness of the game status, in our experience this design has been perceived as overloading and confusing. This issue opens for a wider design challenge: how to find the right balance between the information encoded in tangible representations and information represented as dynamic intangible ones (e.g. on small embedded displays). Furthermore it is important to pay attention to the symbolic and iconic representations to adopt. For example we used a discrete color-coded scale to symbolize ranges of values (panic levels). Being the information only updated when a threshold is reached, most of players experienced this design choice as a frustrating lack of feedbacks from the system. Though this is a general HCI problem, it takes a different connotation when using a TUI approach which poses stricter limitations compared to GUIs to the design space [31]. The design choices for tokens' intangible representations can be influenced by a specific technology, by the physical affordances of the token, or to add a fun factor. Again, there is a subtle balance to reach when designing tokens to control effectively the game, to gain overall awareness of the game status, and to promote fun and engagement.

Lack of technology toolbox. During implementation we were challenged by the current lack of technologicaltools to assist designers in the development of digital board games based on the token-constraint approach. In order to build tokens that afford for the interaction events required in *Don't Panic*, we had to use multiple hardware platforms, different coding languages and to hack the Sifteo platform. Although this modus operandi was coherent with the goal of rapid-prototyping *a token-based game* to validate our approach, it poses limitations to the generalization of our approach and high entry-barriers for designers. The lack of a technology toolkit might create barriers to the implementation of a planned sequence of interaction events (step two of the defined design process). For example, the use of Sifteos as tokens in *Don't Panic* required adding a final step, pushing the upper surface of the cube to signal the operation was terminated, when moving the token between nodes; thus creating a breakdown in the user experience.

8 CONCLUSIONS AND FUTURE WORK

In this paper we present the interactive-token approach to the design of board games. The proposed approach provides a change in perspective from mainstream interactive board games, which are centring design on interactive surfaces. Our approach relies instead on physical manipulation of interactive objects on conventional surfaces, with the aim to preserve the physical and social affordances that are the basis for the success of traditional board games.

The work builds on the Token+Constraint interaction approach defined by Ullmer [4] and the MCRit model [32] proposed by Ulmer and Ishii. In this perspective, it demonstrates the applicability of this combination in the specific domain of board games.

The main contribution of this paper is in the extension of the Token+Constraint interaction approach with constructs that can be used by designer to augment board games with interactivity in accordance with the game rules. These constructs are intended as a way to describe games, supporting the transition to implementation. In addition, the approach suggests a design process for board games.

The approach proposed in the paper has successfully supported the design of Don´t Panic in terms of tokens, constraints, and interaction events. Results from the evaluation reveal that the social affordances of traditional board game are preserved and the addition of computer interactivity is well accepted.

The design and implementation of the game served as evaluation of the feasibility of the approach and allowed us to identify a set of design challenges and opportunities that can be useful to other designers.

As part of our future work, we aim to generalize the approach. Starting with the experience discussed in this paper, we aim at capturing the general game elements into a grammar for mapping sequence of interaction events to game dynamics; and a technology toolkit supporting game designers in the creation of board games as a system of token and constraints.

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Paper 6

Context Becomes Content: Sensor Data for Computer Supported Reflective Learning

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Context Becomes Content: Sensor Data for Computer-Supported Reflective Learning

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Abstract—Wearable devices and ambient sensors can monitor a growing number of aspects of daily life and work. We propose to use this context data as content for learning applications in workplace settings to enable employees to reflect on experiences from their work. Learning by reflection is essential for today's dynamic work environments, as employees have to adapt their behavior according to their experiences. Building on research on computer-supported reflective learning as well as persuasive technology, and inspired by the Quantified Self community, we present an approach to the design of tools supporting reflective learning at work by turning context information collected through sensors into learning content. The proposed approach has been implemented and evaluated with care staff in a care home and voluntary crisis workers. In both domains, tailored wearable sensors were designed and evaluated. The evaluations show that participants learned by reflecting on their work experiences based on their recorded context. The results highlight the potential of sensors to support learning from context data itself and outline lessons learned for the design of sensor-based capturing methods for reflective learning.

Index Terms—Reflective learning, sensor data, context, learning content, pervasive computing

1 Introduction

Context information is commonly used to adapt learning content to the particular situation of the learner and to provide insights that match the learners' experience and situation [1]. Not only have advances in context acquisition and analysis been mainly adopted in formal learning environments, they also offer potential in work settings that rely on informal learning [2]. In fact, on-the-job training is still the dominant form of learning in many workplaces that require highly specific procedural knowledge and focus on adaptive application of knowledge to the situation. For instance, a carer in a dementia care home facing an aggressive patient might find a person-centric approach to be more appropriate to calm the resident. In this setting, the correct action can only result from experience, i.e. knowledge about the particular resident and similar situations. The required content for learning would be the past experience of the carer. In such workplace settings, can the context, which until now has been largely used to select content, serve as content itself?

In a growing number of personal coaching applications, context data is already the main content. Fitbit[1] and Lumoback[2] are examples of commercially available tools. The Quantified Self (QS) community [3] aims at capturing and visualizing data. While available applications mainly target private life and especially health, additional tools to capture behavioral data at the workplace have been developed by the ubiquitous computing community [4], [5], [6]. However, all these tools and technologies lack an approach for in-depth learning based on context. Learning from context data requires a review and a close examination of the context itself. This approach to learning does not necessarily follow a predefined goal but draws insights from the available context data.

This article describes an approach to utilizing context as content by using reflective learning theory to facilitate in-depth acquisition of procedural knowledge and support behavioral changes at work. From a theoretical perspective, Boud et al. [7] define reflective learning as *those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations*. In our methodological approach, we outline three main design decisions to build applications that can support reflective learning by capturing context at the workplace. This approach was used to implement applications for two different workplace environments: dementia care and crisis preparedness. The conducted evaluations in the respective environments revealed that employees can learn from captured context data.

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1. www.fitbit.com
2. www.lumoback.com

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In the following, we provide a brief overview of reflective learning theory and how context can facilitate reflective learning by drawing from persuasive technology, the Quantified Self community, and research on computer-supported reflective learning. Drawing on this background, we present the three main design decisions and related challenges. After briefly outlining our research approach, we discuss two use cases which serve as starting points for the application of our approach to the design of two context-capturing applications: CaReflect and WATCHiT. We describe the design, evaluation, and results of both applications before we summarize our lessons learned and review the impact on learning. The conclusion summarizes our investigation.

2 Theoretical Underpinning

Reflective learning has been a research topic since the work of Dewey [8], which describes how we learn by comparing our expectations to new experiences. This section provides a brief overview of the available reflective learning theories and introduces a model for computer-supported reflective learning.

2.1 Reflection Theory

According to Boud et al. [7] the reflection process has to be understood in relation to the experiences reflected upon and the resulting outcomes. The reflective process consists of three stages in which the learner re-evaluates experiences, eventually gaining outcomes. Outcomes are mainly intangible, like the experiences and the reflection process itself. For instance, a new perspective only becomes apparent by articulating it or by a change in behavior. Outcomes may lack the commitment to action and remain hidden in the first place. However, these changes in the cognitive framework of the learner will influence the behavior in the long term.

Kolb [9] also describes experiential learning in the form of a cyclic process: the so-called Kolb Cycle. The Kolb cycle defines reflection as a process that involves not only reinterpreting existing experiences, but also the initial perception and interpretation of the raw experience. This cultivation of the capacity to reflect in action (while doing something) and on action (after you have done it) has become an important feature of professional training programs in many disciplines [10]. A more detailed description and discussion of existing theories can be found in [11].

2.2 Computer-Supported Reflective Learning

The MIRROR project [12] has developed a model for computer-supported reflective learning (CSRL) [13] which describes the reflection process as a cycle and presents the possible support categories in the workplace. Figure 1 depicts the 4 stages of the reflection

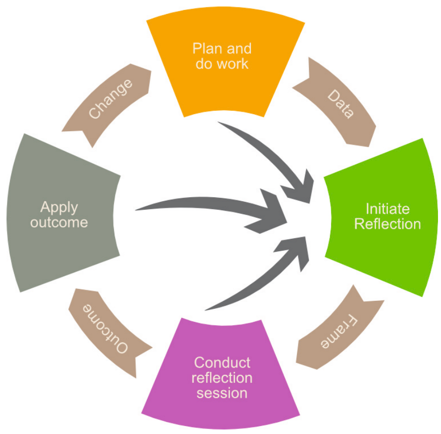

Fig. 1. CSRL cycle by Krogstie et al. [13]

cycle described in this model. In this cycle, the data captured in the *plan and do work* stage is used to initiate reflection and is transformed to provide a frame for the reflection session. The outcomes of the reflection session are applied to change work practices. A reflection session refers to the time-limited activity of reflecting – whether short or long, informal or formal, planned or spontaneous, individual or collaborative.

Reflection triggers are a critical element of the model because they initiate the reflection session (see central arrows depicted in Figure 1). Reflection can be triggered in several phases: during work, while an outcome is about to be applied, or during the reflection session itself. For instance, collaborative reflection in a team meeting may trigger individual reflection of a participant or reflections about organizational topics. The transitions between these three levels (individual, collaborative and organizational) are discussed in [14].

While there are different options to support reflection, e.g. by guiding reflection [15], this article focuses on the capturing and presentation of relevant data. Therefore, the addressed question focuses on the first stages of the model. How can computer-based technology generate content for reflective learning? According to the CSRL model presented above, the data collected on the learner's context in the *plan and do work* stage is captured and processed to provide alternative perspectives on past experiences. This context encompasses a wide range of information, or as Abowd et al. define it: *Context is any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves* [16].

Developers of CSRL applications face the challenge to select, record, and visualize context in a form that

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optimally complements the experience of the user during the *initiate reflection* and *conduct reflection session* phases. Boud et al. [7] do not explicitly define the beginning of the reflection process because *most events which precipitate reflection arise out of normal occurrences of one's life.* However, the provided examples can be linked to the cognitive dissonance theory [17]. The cognitive dissonance theory describes how a mismatch between attitudes and behavior can lead to rethinking attitudes and experiences. This mismatch is perceived as psychological discomfort (dissonance) and motivates a reconsideration of existing attitudes. CSRL apps can offer rich data to support a triggering of reflective processes by raising awareness and inducing cognitive dissonance.

3 Related Work

The initial idea to learn from sensor data is not new. Indeed, we see many sensors and mobile applications that collect data to provide new insights, ranging from fitness to health applications.

There are first prototypes that directly support reflection [18], [19] and approaches to guide design [20]. Capturing tools like the SenseCam [18] have explicitly supported reflection by capturing images. Echo [19] is a smartphone application for recording experiences in the form of pictures, text descriptions, and ratings of emotional state. Furthermore, Fleck and Fitzpatrick [20] developed a framework on reflection and guiding questions to design for reflection. However, the presented approaches either target the private life or are focused on passive image capturing as the support for reflection. They consider neither the whole plethora of capturing opportunities nor the particular challenges of the workplace.

Persuasive technology and Quantified Self applications provide pragmatic approaches to collecting meaningful data that influence user behavior and are often related to reflection and learning. However, these applications lack the theory to cover the wide variety of applications in learning as well as a methodological approach that guides their design for diverse workplace settings. The integration of these approaches from persuasive technology and the Quantified Self with reflective learning theory can facilitate learning from a wider range of sensor data to address the specifics of a selected workplace.

3.1 Persuasive Technology

Persuasive technology refers to *computing systems, devices, or applications intentionally designed to change a person's attitudes or behavior in a predetermined way* [21]. Self-tracking is the most prominent approach to technology-supported behavior change. In terms of the CSRL model, self-tracking in persuasive technology directly connects captured data to predefined outcomes. Visualizations are designed to directly trigger the target behavior instead of reflection. Due to the fixed outcomes, persuasive technology is limited to application domains where strict adherence to rules results in clearly measurable progress, e.g. in healthcare [22], [23]. Ubifit [22] aims to facilitate physical activity by displaying the activity measured by an acceleration sensor and biosensors on a smartphone. MAHI [23] helps individuals with diabetes to track glucose levels.

A predefined target behavior is the starting point for design strategies to create persuasive technology. The theory-driven design strategies by Consolvo et al. [24] provide guidelines for the development of persuasive applications. The iterative step-by-step approach by Fogg [25] begins by choosing a simple target behavior and continues by refining the definition of this target behavior in subsequent steps before selecting an actual technology. According to Fogg, the selection of a simple behavior is crucial, because *many projects are too ambitious, and thus are set up for failure* [25]. Hence, designing for reflective learning may take a similar step-by-step approach but requires additional guidance.

3.2 The Quantified Self

Sellen and Whittaker argue that life-logging should target specific goals, among which they mention reflection and reminiscence [26]. Recently, the growing number of life-logging tools, i.e. tools to track personal data generated by our everyday activities, simplify the process of tracking. A wide range of personal data like exercise, food, mood, location, sleep, alertness, productivity, and even spiritual well-being can be logged and measured. These approaches may not be deliberately designed to change behavior or trigger reflection, but they target similar challenges.

The community of users and developers around these tools is called the Quantified Self (QS) [3]. Their philosophy can be summed up as *self-knowledge through numbers*. They use these tools to conduct experiments with the intention to learn about their own behaviors, habits, and thoughts by collecting relevant information related to them. The QS initiative is not driven by scientific theories, but it is based on empirical self-experimentation. Their inherent curiosity about themselves drives the QS community to explore and reflect on their data. In some cases, a goal-driven motivation is pursued (e.g. losing weight, controlling a particular disease). In many other cases, it is just the enthusiasm for technology and data that drives this quantifying behavior without having identified in advance any concrete benefit from it (e.g. track any kind of social contact with other people or which streets of a particular city have you already passed by). A selection of prominent tools used in the QS community is shown in Figure 2. Choe et al. [27] provide a more comprehensive overview of QS tools and practices.

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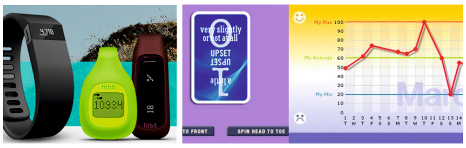

Fig. 2. Popular QS tools: Fitbit family of activity and sleep trackers (left). Moodscope, a mood tracking and sharing web application with mood measuring based on a card game (right).

The QS approach and corresponding tools come under a variety of names, including personal informatics, living by numbers, self-surveillance, self-tracking and personal analytics [28]. In a study by Li et al. [29], *participants collected different types of data so they could figure out the correlations between them*. This deliberate broad capturing of data with an explorative mindset is linked directly to the challenges faced in CSRL.

Nonetheless, the workplace setting imposes additional constraints that inhibit the iterative and open-ended development pursued by the QS community. The QS tools are not intentionally built to support reflective learning in a particular work environment and therefore many challenges and barriers are not considered.

4 From Context to Content: A Methodological Approach

Designers of reflective learning applications for a workplace have to map the requirements from reflective learning theory to the opportunities provided by context capturing within the constraints of the specific workplace environment. While they can learn from design guidelines for persuasive technology [24] and the analysis of successful QS tools [27], a methodical guidance is required to analyze requirements and evaluate opportunities. Workplace settings provide a plethora of opportunities to capture data for reflection. Many activities are already recorded and documented for legal reasons; others can be captured by additional tools or changed processes.

Figure 3 visualizes three major design decisions that have to be made to turn context captured in the *plan and do work* stage into visual support for the subsequent stages (*initiate reflection* and *conduct reflection session*):

- Which context should be captured?
- How can this context be captured?
- How can the context be visualized?

These decisions depend on each other and the targeted work context. The following sections describe our approach by describing promising options and highlighting related challenges for the three decisions.

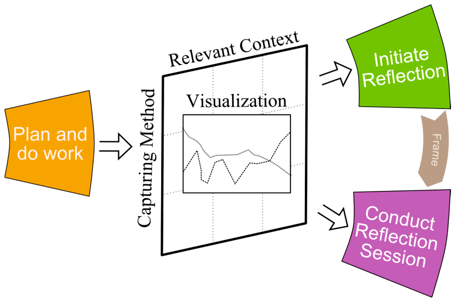

Fig. 3. Design decisions to turn context into content, in relation to the CSRL model.

4.1 Relevant Context

Depending on the workplace and use case, different types of data are relevant. Moreover, the relevance of context depends on yet unknown goals. This *relevance paradox* [30] complicates the decision on two levels by (a) the unpredictability of relevance of context and (b) the subjectivity and need for interpretation of context.

Unpredictability of relevance: Similar to the usage of QS tools [27], the outcome of reflection cannot be precisely predicted; (i) it is unclear which context is useful and (ii) more context information has to be captured than will probably be used afterward.

Subjectivity and need for interpretation: It is inherently difficult to identify data that relates to a particular experience. While hardware sensors and IT systems can capture a growing part of the context, the perception and interpretation of this context is hard to estimate. The user's perception depends on existing experiences and biases. Only the user can provide the necessary feedback to select the relevant subset of data for later reflection, and in many cases, this selection is already part of a reflective learning process. Hence, designers cannot solely rely on fully automated ways of capturing (such as hardware sensors or mining of existing data), but have to look at applications that involve the user into this process or combination of sensors that provide hints on the relevance.

Three types of context have been identified that may act as memory support or help to recognize relevant time spans for reflection at the workplace: task, affective and social contexts. *Task context* relates directly to the work process and is, therefore, easy to understand for employees. Used tools can be augmented by additional sensors or existing data from project management tools can be reused. For instance in crisis management, rescue-related devices like a stretcher could be augmented with sensors. Alternatively, in a care home the care documentation could be reused. However, there is the risk that this data could be seen as an undesired performance monitoring by employees. If the data is seen as only beneficial for the management board, the acceptance of the corresponding apps will be low.

The capturing of *affective context* can be applied in a broad range of workplaces, e.g. by using sensors [5]. If something important happens during the day, it will likely trigger an emotional reaction. Therefore, affective context data can act as a marker to recognize relevant time spans and relevant situations for reflection. Furthermore, emotional awareness and emotion regulation are desired goals in many workplace settings. However, this data is highly privacy sensitive.

Similarly broad in the application domain is the *social context*. Social contacts are a vital part of our work. Whether we talk to colleagues, customers, or partners, these interactions are often decisive parts of the daily work. In some workplaces, these social contacts will basically mirror the task context, e.g. nearly all tasks of a nurse are related to a patient. Hence, similar limitations related to task context mentioned above apply regarding the acceptance of the data.

4.2 Capturing Method

The decision about which context data should be captured in the *plan and do work* stage is closely tied to the possibilities of capturing this data. The preferred capturing method has to be as unobtrusive as possible while providing the desired amount of details. In-depth insights regarding long-term trends might only be possible after several months (or years) of data capturing. Employees receive the benefit for their capturing efforts only after a certain time. Moreover, this benefit is not guaranteed because of the unpredictability of relevance and the subjective interpretation of the data. The selection of the right capturing method is the key to the acceptance of a CSRL application. The options to obtain the desired data can be broadly classified into three methods:

- Data can be captured by the user, i.e. *self-reported*, thus providing a subjective impression of the current situation. The used tool can be a diary containing detailed personal notes or just a personal checklist.
- Data can be captured by *self-reporting from third parties* and made available to the reflecting person. This external perspective can be provided by single individuals or in an aggregated manner by multiple sources, e.g. in the form of a survey.
- Data can be captured *automatically* by sensors and applications, e.g. a simple log file recording all computer-based activity or an activity sensor.

These three methods have to be analyzed depending on the nature of the desired data as well as the environment where the data should be collected. The required effort by the user to obtain the relevant data for reflection varies across the three methods. Self-reporting apps rely on the user and therefore require their motivation, and this motivation has to be kept high over time. The Quantified Self community has presented a wealth of data and the possible insights that can be gained by highly motivated users. Accordingly, the integration into the existing work process is a key to success for self-reporting apps. An observer-based method distributes not only the required effort for data capturing to third parties, but the motivation challenges as well.

Automatic capturing methods shift the main effort from the employee to the investment and maintenance of technology. In many cases, additional software and hardware are required which might need experts to manage them. Automatic methods allow a wide range of granularity and precision, e.g. technology can be configured to capture data at any supported sampling rate. Often the main challenge is rather to filter the captured data or to find visualizations to aggregate large amounts of data. In contrast, constant self-reporting will interfere with the daily work.

Nevertheless, self-reporting apps can be applied across a wide range of workplace settings. In contrast, automatic methods are often tied to a particular tool, e.g. the computer, or a particular environment. Notable exceptions are wearable sensors and devices that can accompany an employee across different places and contexts. These wearable devices are well suited for dynamic work environments like care homes and crisis management where most employees are mobile and generally do not use smartphones or tablets in their daily work.

4.3 Visualization of Context

As suggested in [31], attractive and intuitive presentation and visualization forms for the users should be chosen, which at the same time foster the analysis of the data. Otherwise, this can become one of the major barriers in the *initiate reflection* and *conduct reflection session* stages. In addition, context visualization can benefit from the vast research visualization techniques, but further research is needed to assess the added value of these visual approaches in terms of effectiveness, efficiency, or other criteria that pertain to learning [32], especially in informal learning. Consequently, visualizations to support learning need to be developed by *using a user-centered design approach*, resulting in several prototypes and iterations which are affected by the feedback of end users. The concrete background of the learner, as well as her knowledge of the data, has to be taken into account.

Data can be visualized from several perspectives, depending on the criterion or criteria taken into account. Visualizations of surprising data or unexpected perspectives can lead to cognitive dissonance [17] and trigger reflection [24]. Hence, designers should aim to outline deviations and help to understand the underlying reasons. In [31] the following most *common visualization perspectives* were analyzed and

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summarized: Social perspective (comparing own performance/measures with others or aggregating data over multiple users), spatial perspective (the location of the user, allowing to understand the relation between place and behavior), historical perspective (comparison of current values to historic values), meta-level perspective (using item metadata that supports the understanding and interpretation of the data) and external perspective driven by other data sets (visualization according to data provided by other standard sources of information like e.g. the weather). In some cases, there are already established visualizations, which have proven to be intuitive and accepted, e.g. timelines for the historical perspective or social networks for the social perspective. However, other types of context can result in more complex visualizations, which have to be adapted to the type of captured data as well as to the learner's background.

For choosing the correct visualization, it is also important to *know from the end users which kind of questions they would like to get answered* by analyzing the data. This will guide the selection of the appropriate visualization. In the care domain, we have experienced in our studies that carers would like to know which patients they cared for and how long it took. Consequently, the time component should be easy to interpret in the visualizations. The studies conducted in the crisis management domain revealed that the exact time needed for each task compared to the optimum time was of most interest, so both values had to be easily and quickly comparable in the designed visualizations.

5 Research Approach

Many workplaces have benefited less from the developments in technology-enhanced learning because they are highly dynamic and rely on on-the-job-training. Two examples are care professions [33] and volunteers in crisis management [6]. Formal training material can provide guidance, but this education mainly trains the application of this knowledge in highly dynamic environments. Reflection on made experiences is crucial to draw as many insights as possible from every situation. Carers and volunteers have to work as a team to target the upcoming challenges and apply their knowledge to similar situations.

The following Chapters 6 and 7 describe two design studies in these work environments, i.e. dementia care and crisis management. Both chapters outline the specific challenges in the domain and motivate the resulting reflection practices before the developed application and its evaluation are presented.

5.1 Application Design

For each use case, one application was developed according to the design approach presented in Section 4. Two independent research groups designed and implemented the two applications. Both groups followed a user-centered participatory design process by iteratively creating prototypes and conducting preliminary studies. With this approach, we aimed to test our prototypes as often as possible in the target environment, as suggested by Rogers et al. [34].

Initially, developers visited the work environments to collect requirements and understand the needs of end users. Mock-ups and prototypes were iteratively refined in small studies with end-users and experts from the fields. In this process, sensor technology became more robust, and visualizations were tailored to end-user requests. The implementation resulted in two tailored solutions, CaReflect and WATCHiT, that differ in their selected options depending on the use case. The preliminary studies in a care home have been presented in [35], and the studies in the crisis management domain have been reported in [36].

5.2 Evaluation Method

The evaluations reported in Chapters 6 and 7 tested the developed applications in the respective work settings to measure user acceptance, usability of the system, and impact on learning. We used a mix of qualitative and quantitative methods to account for the unpredictability in an in-situ study [34]. Hence, we combined sensor data, observations, questionnaires, and interviews to gain an in-depth understanding of the application usage and impact. Questionnaires offered a high-level quantification of feedback, while observations and interviews aimed to ground this feedback in the context of usage. Furthermore, researchers encouraged users to articulate insights and comment on their actions during the reflection.

The evaluation of CaReflect and WATCHiT was performed using the MIRROR evaluation toolbox [37], which provides questionnaires that measure reflective learning at work. These questionnaires are a generic instrument that has been developed through an extensive survey of literature on reflective learning and in cooperation with participants from different workplace settings. The resulting framework builds on the Kirkpatrick framework [38] and the theoretical understanding of computer-supported reflective learning described in Section 2.2. In this way, it is possible to study the impact on learning at different levels, e.g. perceived usefulness vs. willingness to change. Renner et al. [39] describe the application of the toolbox in a workplace setting different than the two addressed in this paper. The resulting toolbox includes a core set of evaluation questions and a large set of optional and tailorable tools. In this paper, given our research focus, we only consider questions for measuring user acceptance, perceived learning success, and the intention to change behavior. User acceptance was measured using the *net promoter score (NPS)* [40] as to whether participants would recommend the used system to

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their peers. The questions regarding learning and intended behavior change had to be rephrased for the care home domain. Care home managers deemed the original wording as too complex. The questionnaire items used a five-point Likert scale (from 1=strongly disagree to 5=strongly agree) and are reported with mean and standard deviation (SD).

Interviews were used to follow up on the questionnaires, the observations regarding outcomes gained during tool usage, and the potential to use the application in the long term. The interviews helped to verify statements and ask for specific outcomes that can come in various forms according to Boud et al. [7].

6 Design Study: CaReflect

Carers in a care home rarely take the time to sit down and reflect, because the requests of the residents have always a higher priority. The CaReflect app was designed to support carers in care homes by reflecting on their daily interaction with residents and colleagues. A single sensor is used to capture the social context and provide an objective perspective on own care practices by visualizing the data captured to the care staff.

6.1 Dementia Care

As in the rest of Europe, the life expectancy of the average care home resident in the UK is rising, with a concomitant increase in the incidence of dementia, an age-related cognitive disability [41]. Around two-thirds of nursing and care home residents will have some form of dementia, putting additional strain on the care staff, due to the unique and complex challenges such a disability can cause.

Most staff members in a care home are care assistants. Except for recently qualified nurses, they are not educated to degree level and only have national vocational qualifications. As a result, staff without formal training can be confronted with complex situations to resolve. Work is organized in two day and one night shifts with handovers; protocols document every treatment and activity. A high turnover of care staff – around 20-25% annually is common for homes in the sector [42] – so most homes will always have a significant number of inexperienced and new staff.

Although often paid around the statutory minimum wage, a new care worker is expected to undertake an induction period and then training in some 13 or more mandatory areas of professional knowledge in their first two years of work, ranging from 'manual handling' to dementia care and 'end of life care.' Induction will involve the supervision of experienced carers as well as knowledge-based training. While e-learning is increasingly a part of this training, most training is still of the traditional small-group type with a specialist trainer presenting for a half-day or more. However, such general approaches cannot cover all the variants of challenges likely to be posed to the staff from the residents and their unique demands. These challenges often require some reflection and some help, for example, asking experienced staff.

A growing challenge for care homes is the higher proportion of increasingly elderly residents suffering from dementia when admitted to the homes. This can lead to instances of challenging behavior where the elderly residents are confused and react, sometimes aggressively and irrationally, to their unfamiliar surroundings. Reflective learning on the side of the carers and nurses working in the homes is seen as a potential, as there is no one-size-fits-all solution when dealing with personalities approaching the end of their lives with their individual and complex life-histories [33].

6.2 CaReflect

The system is based on proximity sensors as presented in [4], [35]. The proximity sensors are wearable devices – either in the form of a badge or wristwatch (see Figure 4) – that capture the proximity between wearers of the sensors. Every 10 seconds the environment is scanned for other sensors that are worn by residents, carers, or placed at important positions, such as the documentation desk. The sensors store all contacts and can be read afterward by the CaReflect system. The data provides an objective perspective on the daily interaction by quantifying the contact times. Furthermore, sensors can be placed at critical locations like the office or on used devices such as the laptop that is used for documentation tasks.

The resulting data can be analyzed using the CaReflect platform. The platform is a Java-based application running on a laptop as part of the sensor station (4-c). Carers have only limited time to review the data and want to be able to check their work at a high level. Typical questions are: Who needed most time today? How does the effort for this resident relate to the time spend with other residents? Is there someone that I might not have seen at all? How much time did I spent on documentation?

Carers asked for a pie chart as a brief summary of their day. Only if the pie charts were surprising, carers would like to see additional visualizations to explore the underlying reasons, e.g. when did they spend time with a particular resident? For this purpose, the system visualizes the time spent with residents and colleagues in the form of timelines (see Figure 4-d) and pie charts that summarize the day. Carers can browse through these timelines individually. However, carers may ask colleagues about specific patterns. There are also separate tools to create custom timelines, e.g. a timeline showing all care that a resident received.

6.3 Evaluation in a Care Home

The CaReflect App was tested in a nursing home over four days during all three shifts. It was used by 40

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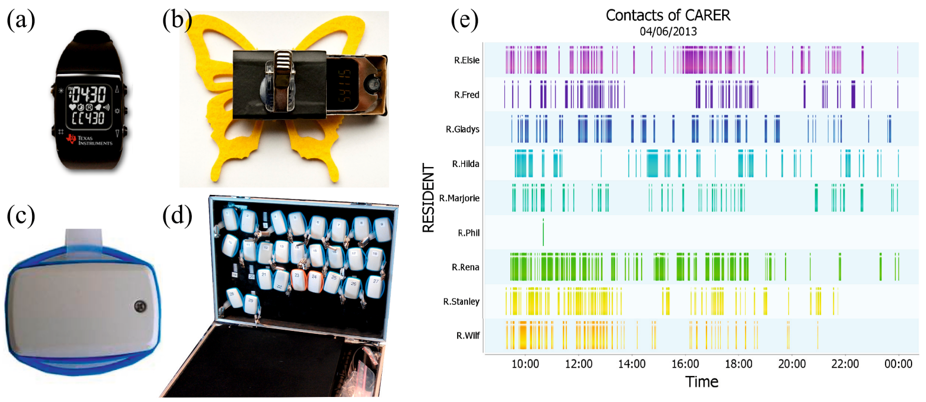

Fig. 4. CaReflect prototypes and visualization: (a) sensor original format, (b) first prototype, (c) final sensor hardware prototype, (d) mobile sensor station, and (e) visualized timeline showing the contacts of a carer with each patient.

carers (34) and nurses (6) mostly female (2 male/38 female), with varying degrees of care experience (4 months to 27 years), and coming from a wide range of age groups (<20 : 6; 20-29: 11; 30-39: 7; 40-49: 6; 50-59: 6; >60: 3). Each staff member was wearing a proximity sensor during the shift. Nine residents with different levels of dementia and different needs for care were selected by the care home staff. These residents were coming from all of the four wards of the care home. Further sensors were placed in the staff office and in the common rooms on each ward to obtain insights on the location of staff. Documentation is either done on a laptop in the common room or in the office.

At the beginning of each shift, care staff had to log into the CaReflect system to get a sensor at the sensor station, shown in Figure 4-d. On the first day, carers managed the distribution of sensors. During the study, they regularly checked if the sensors were still attached. After each shift, participants returned their sensors to load the data into the CaReflect system. They were asked to reflect on the recorded data directly after their shift and to complete a short questionnaire. One week after the study, a subset of the participants (17) were interviewed to provide additional qualitative feedback and fill a concluding questionnaire. The interviews were limited to 20 minutes because of work constraints. During this time, the aggregate data from the system was shown and participants provided feedback on the physical sensors, usefulness of the system for triggering reflection, and insights gained.

6.4 Results

User acceptance and usability was measured in the concluding questionnaire and interviews. Participants were satisfied with CaReflect (3.82, SD=0.6) and 82% said they would like to use CaReflect again with their team. Only 24% said they would like to use it on their own. Every day seems different for the carers, dependent on the health, activities, and moods of the residents. The data, shown on a day-by-day view, often stimulates the carer to provide a narrative of this specific day (e.g. *"this was the day Allan died," "this was the day Doris didn't want to get up," "this was the day I spent ages in the office talking to John's daughter,"* etc.). The concluding interviews provided additional qualitative feedback to understand the results better. For most carers, the benefit was to see the measured and relative time given to residents, spent with other staff, and at various locations, particularly 'the office.' A number of carers said it was difficult to remember all their contacts over an 8-hour shift, particularly when encouraged to work in the 'butterfly' mode, i.e. a large number of small contacts rather than large blocks of single contacts.

The overall net promoter score was negative (NPS =-29%). This result is due to the many young detractors (5) among the inexperienced carers (9 of 17) that did not see any value in the collected data. Experienced staff members (8 of 17) were neutral (NPS = 0%). These experienced staff members include all nurses and care coordinators.

The knowledge of the individual needs of residents is used to evaluate the CaReflect data – this is where reflective learning occurs most clearly. The quantitative results of the questionnaires indicate that carers in general agree on the impact of CaReflect on learning (4.03, SD=0.55). In individual reflection sessions, care staff reviewed the time shares allocated to each resident and came to outcomes. For example, one carer noted that a particular resident with a sensor seemed to receive more attention than usual,

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TABLE 1
Responses split by experience of participants

Question	All (n=40)	Experience $\geq$ 5 years (n=12)	Experience <5 years (n=28)
I learned something by looking at this data	4.03 (SD=0.55)	4.18 (SD=0.39)	3.96 (SD=0.60)
I have now an idea what I could change.	3.66 (SD=0.85)	3.77 (SD=0.91)	3.61 (SD=0.82)

and responded by being more alert and brighter. When asked for examples of insights, carers talked about the time spent on documentation or the differences between residents. One carer was surprised how much time she needed to assist a resident with meals and wanted to discuss with colleagues about their experiences. While collaborative reflection was not planned as a formal session, individual reflection sessions motivated carers to reflect collaboratively during their daily care. However, fewer staff members felt that they had an idea how they could change their behavior (3.66, SD=0.85). One example that was reflected even with the manager but did not yet lead to a decision was the need and amount of 'doubling up' given for heavy, difficult or highly dependent residents. Learning and reflection occurred at all levels, but insights and acceptance varied between participants. When the questionnaire feedback is split into experienced carers with at least five years of experience (12 out of 40), it becomes apparent that especially the experienced carers see more benefit in using CaReflect (see Table 1).

7 Design Study: WATCHiT

WATCHiT is a wearable computer for situated collection of data in crisis management. It allows emergency workers to capture information while being in the field and without interrupting the rescue work. Data captured might include self-reported information from the individual, for example, perceived stress levels; and automatic data captured from the environment, like locations, temperature, time, and radioactive exhalations. For a description of user studies and development of an early prototype, see [36].

7.1 Crisis Preparedness

Over the last 35 years, the frequency of natural and man-made disasters has increased five-fold and the damage caused has multiplied by approximately eight times [43], making preparedness to crisis management a priority for all European countries [44]. Public administrations at different levels (e.g. municipality, regions and national bodies) are facing growing responsibilities for preparedness, struggling with old and emerging risks and limited resources.

An important part of preparedness is proper training. Training for crisis preparedness is challenging not only because of the complexity of the work to be performed, but also due to its sporadic and discontinuous nature, which makes it difficult, if not impossible, to assure that workers gain sufficient experience. To compensate for the lack of real experience, drills and field tests to recreate realistic crisis experiences are often adopted. Drills and field tests are complex training activities that promote training of different skills for individual workers, as well as an occasion for organizations to test relevant procedures and their capability to apply them. Though learning from (simulated) experience is recognized as critical, it is expensive and thus important to optimize the impact. Additional problems are keeping motivation, lack of time, varied levels of initial competencies, and retaining personnel, especially young people [45], [6]. Reflective learning plays an important role in crisis preparedness, ranging from the sharing of war stories among field workers to highly structured debriefings involving multiple organizations. In our work, we focus on the learning of volunteers while training the execution of medical procedures.

7.2 WATCHiT

Capturing data, both by using self-reported and automatic methods, during crisis response is challenging. First, it is difficult to foresee the type of data that is relevant to be captured. For example, air quality information might be relevant during a wildfire but not during a flooding. Secondly, the introduction of new devices for data collection requires careful study to avoid interfering with highly standardized protocols for rescue operations. Most of the tasks a field worker is engaged in require both hands to be free, for example to carry someone on a stretcher or to break into a building on fire, thus making self-reporting difficult. Thirdly, in order to provoke reflection, the data acquired needs to be reviewed in a way that helps to make sense of the information, reconstruct original meanings, and reflect on alternative paths of actions. However, voluntary workers in crisis situations lack regular time and places of work when this can be done. In order to tackle these challenges, WATCHiT features a modular design based on sensor modules for transient customization of the types of data capturable in the field. The set of information WATCHiT captures is not defined a priori, but can be customized by plugging sensor modules on a technology-augmented wristband (Figure 5-a). In the current prototype, we built modules for sensing location, time, air quality, and to read RFID tokens.

WATCHiT includes a disruption-free user interface that allows the user to control data collection using RFID tokens to be embedded in uniforms or tools (Figure 5-b). Tokens are activated when waved in

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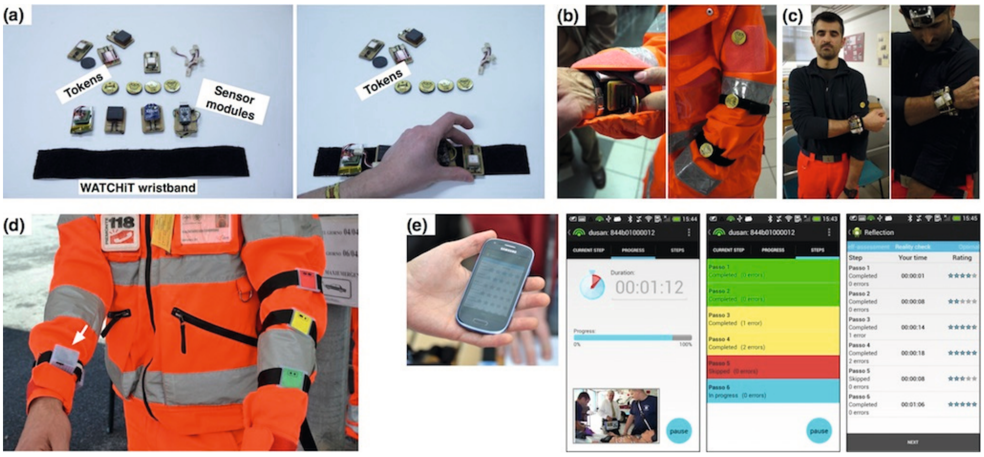

Fig. 5. Modular wearable WATCHiT hardware: (a) physical sensor modules and tokens, (b) WATCHiT and tokens on working uniform, (c) user interaction with the system (d) WATCHiT worn by a volunteer and (e) WATCHiT Procedure Trainer visualizations.

close proximity to the WATCHiT wristband (Figure 5-c). They can be programmed beforehand to control the activation of specific sensors or to bookmark raw data with predefined informational tags reporting on activity or feelings. For example, a worker could tag GPS coordinates captured by the location sensor module with labels like *injured person rescued* or *high stress*. Another example, as shown in the evaluation in Section 7.3, is the use of tokens for collecting the time and self-reported errors during rescue procedure training. The Bluetooth link and developer API enable data exchange with mobile apps than can support quick on-site reflection sessions.

Compared with the CaReflect study, with WATCHiT we investigate the capture of more than one type of context at a time; thanks to the modular design and APIs, WATCHiT can be configured to address the need for capturing different types of contexts in different work practices. Furthermore, using RFID tokens as informational tags, WATCHiT complements the automatic capture of quantitative data with the collection of self-reported qualitative data, leveraging the benefits of the two approaches. This aims at both increasing relevance of data and giving the user more control of the capturing device.

In this paper, we examine WATCHiT integrated with WATCHiT Procedure Trainer, a smartphone app that aims at promoting reflective learning using the data collected through WATCHiT. Workers use WATCHiT with RFID tokens to collect the time taken to complete each step of a rescue procedure and self-report their errors. The application promotes reflection by guiding users through a set of steps: (i) visualization of data captured (completion time and errors for each step) for performance self-assessment and rating, (ii) comparison of each own performance with best practices provided by experts and previous performances by colleagues, and (iii) collection of notes on possible improvements (see Figure 5).

In this way, the app provides a more structured reflection session than CaReflect, where the reflection session is supported only by providing data visualization. On one side, this leaves less freedom to the users to explore the data, but can be more efficient under the strict time constraints of rescue work.

7.3 Evaluation in Crisis Preparedness

WATCHiT together with WATCHiT Procedure Trainer were evaluated by voluntary workers of an Italian emergency association while training for the 'Percorso Trauma,' a procedure to load an injured person onto a spinal board before ambulance transport, for which time and errors to completion are critical for the survival rate of the injured person. Indeed, it is important that the procedure is performed as quickly as possible, but without errors. The procedure is normally executed by a team of three members, where one acts as leader and has the responsibility to supervise the execution of the procedure and to keep the patient's head immobilized until the procedure is completed. The person wearing WATCHiT, which for this experiment was protected by a hard shell, also wore three tokens (Figure 5-d): one programmed for signaling completion of a procedural step with no error, one for signaling step completion with minor errors, and one for reporting competition with critical errors. Tags were color-coded respectively in green, yellow, and

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red for mnemonic aid. After the procedure, the whole team could navigate through the collected data using a mobile phone with the WATCHiT Procedure Trainer app (Figure 5).

The system was evaluated with nine teams of volunteers, all from different associations, encompassing 27 participants (16 male, 11 female). Experience as a volunteer varied significantly in both groups, ranging from one year to more than 20 years. Participants were from different age groups, with the majority between 20-30 (<20 : 1; 20-29: 14; 30-39: 7; 40-49: 3; 50-59: 2). The evaluation was conducted during a large training event and a national championship encompassing simulated rescue operations after an earthquake, where the registered teams were performing different procedures. This type of event is a core part of crisis and emergency workers training and is designed to resemble as much as possible real situations. We observed the teams while performing the procedure and we collected 27 questionnaires to gather feedback on perceived usefulness, usability, and impact on reflective learning.

7.4 Results

The respondents were overall satisfied with the use of the system (4.11, SD=0.49) and perceived it as a useful tool for training (4.22, SD=0.62). The respondents also agreed that the system helped them to reflect on their work (4.00, SD=0.6). The information collected with WATCHiT was perceived as accurate (3.90, SD=0.6), relevant (4.03, SD=0.50), and the collection of data was effortless (3.81, SD=0.47). Respondents agree that the system has provided relevant content for reflection (4.23, SD=0.50).

The net promoter score was fairly positive (NPS = +4%); interesting enough there was a large disagreement between the expert and novice groups. Seven out of thirteen experts recommended the app (NPS= 41%), while we counted six detractors among novices (NPS= -38%). This result is in line with the CaReflect study, and it confirms the milder acceptance for the proposed capturing tools among novices.

The quantitative results of the questionnaires indicate that respondents agree on the impact on learning. After using the system, respondents made a conscious decision about how to behave in the future (4.07, SD=0.62) and gained a deeper understanding of their work life (3.96, SD=0.71). They were also motivated to change their behavior (4.11, SD=0.49). The questionnaire also included some open-ended questions about what aspects one intended to change at the individual or team level. Intention to change included (i) the use of artifacts during the procedure, e.g. tightening the straps of the stretchers, (ii) the procedure, e.g. *"I need to understand better the different steps in the procedure"*, and (iii) higher level skills, e.g. *"more attention"* and more cooperation and coordination, *"for sure we need to cooperate more within the team."* These results are also in line with the observations conducted during the evaluation. While using the application, the teams discussed their performance, trying to make sense of the data in order to learn, for example, how the team should be positioned during the operation or the use of different types of stretchers.

TABLE 2
Responses split by experience of participants

Question	All (n=27[3])	Experience $\geq$ 5 years (n=13)	Experience <5 years (n=13)
I gained a deeper understanding of my work life.	3.96 (SD=0.71)	4.15 (SD=0.55)	3.79 (SD=0.83)
I made a conscious decision about how to behave in the future.	4.07 (SD=0.62)	4.08 (SD=0.76)	4.07 (SD=0.49)

The system stimulated knowledge exchange within the team (4.11, SD=0.41) in the form of collaborative reflection. In particular, we observed that some of the teams discussed their performance while and after going through the steps of the mobile apps. Table 2 provides results from the questionnaires considering different levels of experience.

8 Discussion and Lessons Learned

With the evaluations of the two systems presented in this paper, we have shown that the reflective process can be supported if it is fed with relevant context captured from the work environment. In the following, we discuss the results, and present lessons learned related to the role of context in reflective learning and the three design choices identified in Section 4.

8.1 Learning from Context

Participants in both studies were able to learn from the visualized context. They quickly understood the visualized data and their narratives of events established a relationship between the new perspective and their own experiences. Carers and rescuers reconstructed specific situations and gained new insights while doing so. Consequently, as described in the CSRL model, sensor data can indeed be used for promoting the transition from working to learning.

However, learning outcomes varied within both groups. Volunteers using WATCHiT acquired knowledge about their behavior while performing their work, e.g. about the procedure (the steps to perform) and transversal skills, e.g. the importance of reflection. Carers using CaReflect learned about their work patterns as well as general organizational issues. In this perspective, our experience confirms that learning goals and expected outcomes are difficult to define a priori. Though both applications might be associated with the overall learning goal of getting a better

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understanding of work practices and behavior, the resulting outcomes depend on the particular work situations of individuals or teams. *It is therefore critical when designing tools for reflection to find a balance between defining an overall learning goal (e.g. reflecting on a particular aspect of a procedure) so to be able to identify relevant context data and visualization, and at the same time leaving enough space for exploration while reflecting ('conduct reflection session' in the CSRL model).*

The evaluation of both apps has shown that collecting data alone does not produce reflective learning but it requires time to understand the collected data. This becomes more pressing with growing complexity and richness of data, because learners will need more time for the initial interpretation, and the time to understand it from many different perspectives. From this point of view, it is important to carefully address framing of the reflection session. In the WATCHiT Procedure Trainer, for example, the framing of reflection is partly embedded in the application by implementing concrete reflection steps and enforcing a predefined way to analyze the data. On the contrary, in CaReflect, the framing is only provided in terms of visualization of data, but no predefined navigation steps are defined. This leaves more freedom to users, but it comes to an additional cost, because they need to organize the reflection session, for example how to navigate through the data. *Designing tools for reflection therefore requires a careful tradeoff analysis between providing a structured reflection session versus a more open-ended one ('initiate reflection' in the CSRL model). There is no one-fits-all solution, since the right type and degree of framing might depend on the type of work, the conditions under which reflection is performed, and the experience of the users.*

In both design studies, the participants engaged in making sense of the data, individually and collaboratively, and the data were compared and integrated with memories from the actual work. As memory fades away, it might become more difficult over time to make sense of the collected data. *Therefore, when designing tools for reflection providing for an option to record reflection outcomes becomes important, so that the gained insights can be used later (implementing the outcome arrow in the CSRL model). This can be done within tools, e.g. by adding functions for recording the outcomes of a reflection session, as in WATCHiT Procedure Trainer, or annotating the data.*

In both design studies, learning (as reported by users, see Tables 1 and 2) was higher for experienced workers. This is a counter-intuitive result, since one would expect that people with less experience are the ones who have more to learn. The results, however, show that more knowledge on the work process seems necessary to benefit from reflection. *This should be considered during the design, for example, by adding for less experienced users more knowledge of the process to reflect on, more guidance on the reflection session, or some form of coaching ('conduct reflection session' in the CSRL model).*

8.2 Context as Content

The selection of a context type as the content for reflection is mainly driven by the workplace-specific requirements. *Relevant requirements vary not only across domains but even within domains*, e.g. different care homes involved in the design process pursued different care philosophies. Some care homes strive for long in-depth social contacts, while others aim for many short contacts; known as 'butterfly' method. Therefore, *a user-centered design is required to select the relevant data, capturing method and visualization for the particular setting*.

In the evaluation of WATCHiT, we observed how sharing of visualization could trigger new reflection cycles, e.g. involving other teams or instructors. Nevertheless, *the design of CSRL applications for workplace-settings has to account for the legal and social implications*. For instance, employees may fear legal consequences, i.e. if captured data and annotations can be used against them. Especially in domains like healthcare, all documentation can be used if potential mistakes come to trial. However, participants in both studies lacked awareness of the possible legal and social implications of data sharing. Functionality that aims at enhancing the privacy is mainly seen as a barrier to usage of the system, e.g. anonymized visualizations were perceived as hard to understand during the usage of CaReflect. Especially in the care domain, not sharing data among colleagues is seen as an offense. *Privacy functionality has to be a central part of the systems but adapted to the needs of the particular context*.

Our evaluation pointed out that *by putting the focus on one aspect, there is a risk that the others are neglected*. For example, capturing times to perform a procedure rather than quality; or time spent with a patient rather than quality. The CaReflect results suggest that wearing a sensor and knowing that others are wearing one could affect a worker's behavior. Care staff suspected that it might lead to giving more attention to residents with a sensor. Carers asked to give a sensor to every resident to mitigate this problem. *It is therefore important to find the right set of data to collect, shading light on the different perspectives one should reflect on.*

8.3 Control and Adaptation

The two presented apps differ in their capturing method, but flexibility turned out to be a key design goal in both design processes. If users can modify a solution, they can build their "own" custom solution.

Capturing tools should be easy to adapt. If possible, users will customize and 'hack' the tools to meet their needs. The adaptation of hardware-based capturing methods (sensor devices) to the specific context requires more time, and changes are expensive.

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WATCHiT uses a modular approach to allow for the adaption to users' needs. Sensor modules can be added and exchanged to fit the crisis situation. Additionally, more data can be captured simultaneously. This allows users to deal with the unpredictability of relevance of the captured context.

Simplicity of capturing solutions can facilitate adaptation to a workplace-setting. CaReflect is based on a simple concept, proximity, which was easily understood by care home staff. Therefore, it allowed carers, who had no technical background or training, to modify the system by placing sensors not only on residents, but also at places that are relevant for their work. Hence, they could capture data not only about their interaction with residents but also about time spent on documentation.

Automatic capturing and self-reporting can be combined to balance effort and control. Using WATCHiT, users activate the data collection with a gesture. The user can control when and which data is captured. Furthermore, activating the sensor is increasing awareness about the work to be done. The capturing of context becomes itself a reflection session. In general, the interaction was not perceived as a problem. Still, it would require attention from the user and might increase errors in the collection of data.

8.4 Visualizing for Sense Making

Designers aiming at selecting a visualization that makes sense to the user and their work practices have to take into account users preferences, the nature of the work, and the intended learning goal in terms of expected outcomes of the reflection session. For example, in the care domain it is important to choose simplified visualizations, whereas, in crisis management details are important, and therefore these details have to be clear in the data visualizations.

During the iterative prototype development, *participants requested mainly three types of visualizations: status charts, comparison charts, and timelines*. The status chart was often the starting point for exploring the data, e.g. in CaReflect it was the first step to check quickly if something stands out. Comparisons were initially not included in CaReflect because of privacy concerns. However, participants demanded them to benchmark themselves against others in the sense making process. In WATCHiT, comparisons to a benchmark were a central element to reflect on training success. Intuitive timelines are useful for in-depth analysis what was happening at a particular time and often triggered participants to engage in storytelling about the experience behind the data. In general, it is important to identify a visualization that helps the users to make sense of the data considering that, as explained in the CSRL model, data is supporting the transition from working to learning.

9 Conclusion

In this paper, we presented an approach to record context from the workplace and visualize the data as content for reflective learning, by considering theory as well as available technology and its introduction in the work environment. The development of reflection support can be structured along three design decisions: selected data, capturing method and visualization. We provided an overview of possible options and corresponding design challenges. The iterative refinement of these decisions helped to design two wearable sensor systems that facilitate reflective learning by capturing and visualizing context. The evaluation of these two systems allowed us to validate the presented approach and derive lessons learned.

The articulated insights in our two studies highlight the potential impact of context on reflective learning. The participants used their experience and knowledge to analyze the visualized context and thereby learned and gained new insights about their work.

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Paper 7

A Unified Architecture for Supporting Direct Tag-Based and Indirect Network-Based Resource Discovery

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