EDUCATING THE NEXT GENERATION OF MAKERS – 3D PRINTING WITH MARGINALIZED REFUGEE CHILDREN

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Exploring Making and digital fabrication
from a HCI perspective through an exploratory field study
in refugee camps in the West Bank

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ABSTRACT

This thesis covers *Making@Palestine*, a project in which my colleague Dominik Hornung and myself introduced marginalized Palestinian children in two refugee camps in the West Bank to playful 3D modeling and 3D printing. The goal was to investigate into the potential of Making and digital fabrication in the framing of the research project come_IN which aims at socio-cultural empowerment in developmental settings through constructionist, informal learning processes and associated learning spaces (so called come_IN computer clubs).

By way of a five-week empiric field study grounded in a situated, participatory and practice-based understanding of Human Computer Interaction and the development of Information and Communication Technology, we were able to uncover benefits and chances but also limiting factors of 3D printing and Making in developmental settings: The benefits related to an overarching theme of *self-expression* with the central dimensions *playfulness, approachable complexity, individualization, immediacy and physicality* and *collaboration* as well as *motivation* responsible for the success. The problematic aspects mostly related to the limitations of current digital fabrication systems along the themes of *orientation and camera control*, *lack of coordination and collaboration features*, *usability and UX issues* as well as *the construction and limits of current 3D printers*.

Based on those empirical findings, I derive implications for the design as well as for scaffolding the introduction and appropriation process of future systems for digital fabrication in ICT4D settings.

ZUSAMMENFASSUNG

ZUR AUSBILDUNG DER NÄCHSTEN "MAKER"-GENERATION – 3D-DRUCK MIT BENACHTEILIGTEN FLÜCHTLINGSKINDERN

In dieser Arbeit thematisiere ich *Making@Palestine*, ein Projekt in dem mein Kommilitone Dominik Hornung und ich benachteiligte palästinensische Kinder in zwei Flüchtlingslagern im Westjordanland an spielerisches 3D-Modellieren sowie den 3D-Druck heranführten. Das Ziel war hierbei, das Potential von "Making" sowie digitalen Fabrikationstechnologien im Rahmen des Forschungsprojektes come_IN zu explorieren, welches auf sozio-kulturelle Ermächtigung in Entwicklungsszenarien durch konstruktionistische, informelle Lernprozesse und -Orte (die sogenannten come_IN Computerclubs) abzielt.

Im Rahmen einer fünfwöchigen Feldstudie, die in einem situierten, beteiligungsorientierten und praxisbezogenen Verständnis der Mensch-Computer Interakton verankert war, konnten wir Vorteile und Chancen, aber auch einschränkende Faktoren von Making und 3D-Druck in Entwicklungskontexten finden. Hierbei bezogen sich die Vorteile insgesamt auf Möglichkeiten zur expressiven Selbstdarstellung. Als wesentliche Faktoren für den Erfolg zeichneten: *Spielerische Aspekte*, *zugängliche Komplexität*, *Unmittelbarkeit und Physikalität*, *Kollaboration* sowie *Motivation* als übergeordnetes Thema. Die einschränkenden Faktoren bezogen sich in erster Linie auf *Orientierung und Kamerakontrolle*, *Mangel an Koordinations- und Kollaborationsunterstützung*, *Gebrauchstauglichkeit und Nutzererlebnis* sowie *konstruktionelle Faktoren und Beschränkungen aktueller 3D-Drucker*.

Auf Basis dieser empirischen Erkenntnisse ziehe ich Schlussfolgerungen und Implikationen für die Gestaltung sowie die Unterstützung des Einführungs- und Aneignungsprozesses zukünftiger interaktiver Systeme zur digitalen Fabrikation in Entwicklungskontexten.

PUBLICATIONS

For this thesis, I draw and expand on the following publications I have participated in (they are also referenced in the text):

Konstantin Aal, George Yerousis, Kai Schubert, Dominik Hornung, Oliver Stickel, and Volker Wulf. Come_in@Palestine: Adapting a German Computer Club Concept to a Palestinian Refugee Camp. In *Proceedings of the 5th ACM International Conference on Collaboration Across Boundaries: Culture, Distance and Technology*, CABS '14, pages 111–120, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2557-8. URL http://doi.acm.org/10.1145/2631488.2631498

Thomas Ludwig, Oliver Stickel, and Volkmar Pipek. 3D Printers as Potential Boundary Negotiating Artifacts for Third Places. In *Second Workshop on Human Computer Interaction for Third Places at Designing Interactive Systems Conference 2014*, Vancouver, Canada, 2014b

Thomas Ludwig, Oliver Stickel, Alexander Boden, and Volkmar Pipek. Towards Sociable Technologies: An Empirical Study on Designing Appropriation Infrastructures for 3D Printing. In *Proceedings of the 2014 Conference on Designing Interactive Systems*, DIS '14, pages 835–844, New York, NY, USA, 2014a. ACM. ISBN 978-1-4503-2902-6. URL http://doi.acm.org/10.1145/2598510.2598528

Thomas von Rekowski, Alexander Boden, Oliver Stickel, Dominik Hornung, and Gunnar Stevens. Playful, collaborative approaches to 3D modeling and 3D printing. In *Mensch und Computer 2014 Tagungsband*, pages 363–366, 2014

Oliver Stickel, Alexander Boden, Gunnar Stevens, Volkmar Pipek, and Volker Wulf. Bottom-Up Kultur in Siegen: Ein Bericht über aktuelle Strukturen, Entwicklungen und Umnutzungsprozesse. In Stephan Habscheid, Gero Hoch, Hildegard Schröteler-v. Brandt, and Volker Stein, editors, *DIAGONAL Jahrgang 2014: Umnutzung - Alte Sachen, neue Zwecke*, volume 35. V&R unipress, Siegen, 2014a

Oliver Stickel, Dominik Hornung, Volkmar Pipek, and Volker Wulf. Come _ IN : Expanding Computer Clubs Towards Tinkering and Making. In *Workshop on "Teaching to Tinker" at NordiCHI 2014*, 2014b

Oliver Stickel and Alexander Boden. Exploring DIY and Making practices from a Human-Computer Interaction perspective - A case study on playful 3D modeling and 3D printing with children in a Palestinian refugee camp. In *Do it! Yourself? Fragen zu (Forschungs-) Praktiken des Selbermachens*, Vienna, Austria, 2015

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Part I

THE FOUNDATION

After defining and explaining some central concepts and terms, I explain the intent and scope of my thesis. Subsequently, I give a literature-based state of the art about the pertaining areas such as HCI, Making, ICT4D and the come_IN research project.

1 DEFINITIONS

To start with, I need to explain some terms, notions and concepts which are central to my thesis:

MAKER CULTURE / MAKING / MAKER: The *Maker culture* or *Maker movement* is an emerging subculture that engages in Do-It-Yourself and production activities, usually by way of modern digital fabrication technologies (see below) such as 3D printers (Anderson, 2012). This movement is socio-technical in nature in that it utilizes and develops such technologies but also places great value in doing this in open, democratic community spaces such as Fab Labs or Makerspaces (see below) and emphasizes values such as sharing, learning and teaching, playful and collaborative exploration, mutual support and socio-economic change (Hatch, 2013). Especially based on the latter aspect, the maker movement also incorporates a certain element of counterculture, experimenting with smaller, grassroots-based, localized and individual alternatives to globalized mass production.

Two of the most visible organs of the Maker movement are *MAKE*-magazine[1] and a series of global, frequent conferences-come-faires-come-happenings called *MakerFaires*[2]. People associating themselves with the maker movement often call themselves “Makers”. The Maker culture is related in its values to the much older Hacker movement (Thomas, 2002) but the latter one is more associated with software and computers and less with a substantial variety of physical production as employed by *Makers*.

DIGITAL FABRICATION: *Digital fabrication*, in essence, is the computer controlled fabrication of physical objects. A 3D model is created by way of a Computer Aided Design (CAD) application, subsequently fed into a Computer Aided Manufacturing (CAM) tool which generates toolpaths, i.e. instructions for the actual machine making the physical object. Such machines can be grouped into subtractive and additive technologies. Subtractive technologies such as laser cutters or mills remove layers from a raw material and form the final product in this fashion. Additive technologies such as 3D printers build up the final product layer by layer from raw material such as plastic filament or metal dust. The Maker movement frequently utilizes and further develops digital fabrication technologies which have become

1 http://makezine.com/
2 http://makerfaire.com/

more and more affordable and usable for non-professional users in recent years, not least through projects such as DIY 3D printers like the RepRap project[3] which have their origins in the Maker movement.

A relevant concept for digital fabrication is sometimes phrased as *from bits to atoms (and atoms to bits)* (cf. Gershenfeld, 2005), representing the new opportunities to (easily) make digital designs physical and also to digitize physical things (e.g. by 3D scanning), enabling global sharing, collaboration and distributed production. However, it is important to emphasize that the spaces are not simply about the economics of scale – collaboration, social aspects, communication and similar aspects are equally central (cf. Lindtner et al., 2014).

MAKERSPACES, HACK(ER)SPACES, FAB LABS: All three terms denominate open community space in which to engage in DIY, (digital) fabrication, hacking, making as well as socializing activities. Accordingly, they are equipped with the necessary technologies, not least because many of the machines such as CNC mills are too expensive and / or too big for individuals to acquire.

Hackspaces or *Hackerspaces* represent the origin of such grassroots-democratic spaces which centered around computers, software and related topics such as net neutrality. Since the nineties, more and more Hackspaces are being founded, a movement that started with the C-Base in Berlin[4].

Makerspaces are a more recent development rooted in the Maker movement which expanded the understanding and equipment of such spaces into the realms of physical production, often based on digital fabrication (Schön et al., 2014).

Fab Labs (short for "Fabrication Laboratories") are a concept coined at the MIT by Neil Gershenfeld (Gershenfeld, 2005) and represent the attempt to standardize Makerspaces by way of suggesting roughly similar equipment, open sourced modules to interconnect those machines and open source software (CAD/CAM) to drive them. It is not a formal standardization per se, instead, the main idea is to form a more coherent world-wide community, to facilitate collaboration and to enable Makers to basically walk into each Fab Lab around the world and start to work on project without excessive re-thinking and re-learning. Given their grassroots nature, it is impossible to give a count about the amount of Hackspaces, Makerspaces and Fab Labs around the world but `www.fablabs.io` might serve as a landmark, counting 435 Fab Labs world-wide at the time of writing.

3 `www.reprap.org`
4 `https://c-base.org/`

3D PRINTING: *3D printing* represents a wide variety of technologies that build up a physical 3D object layer by layer. Technologies include *Selective Laser Sintering* (SLS) in which a material such as metal dust gets sintered (heated to just below melting point) with a laser which produces hard metal layers. Similar technologies can be employed with stone-like or plastic materials. There are many more 3D printing technologies but the most prevalent one in the Maker culture and hence in Makerspaces and Fab Labs is *Fused Deposition Modeling* (FDM). In essence, this technology works similar to a hot glue gun: Plastic filament is fed through a heated nozzle (*hot end*) by a motorized extruder, thereby gets molten and subsequently deposited layer by layer in computer controlled paths to form a 3D model.

Through the recent expiration of certain patents, FDM printers underwent rapid price drops and wider availability – at the time of writing, such machines with a build envelope of about 20x20x20 are available for prices as low as 300 USD. Common printing materials are ABS (the same plastic that is used in Lego) and PLA (a corn starch based bioplastic) but there are more exotic materials available that e.g. incorporate wood or stone.

LASER CUTTING / ENGRAVING: *Laser cutting and engraving*, unlike 3D printing, represent subtractive digital fabrication technologies: A computer controlled, high-powered laser is used to cut materials very precisely and repeatable or just to engrave (*mark*) them, if used at lower power settings. With enough power, most materials can be cut but in the price as well as danger range acceptable for typical Makerspaces and Fab Labs, machines that can cut about 5mm of acrylic are typical.

OPEN SOURCE: *Open Source* is, at its basic core, an approach to the development of artifacts which incorporates free, open and universal access to the artifact's blueprints, specifications and/or source code as well as the re-usability and modifiability of those sources by anyone (Laurent, 2004). Especially in (open source) software development, a significant, deep and sometimes quite hard discourse about different viewpoints on open source has evolved[5]. For the intents and purposes of this thesis however, the initial and basic definition will suffice, especially given that the Maker culture, Fab Labs, Makerspaces as well as digital fabrication technologies are rapidly evolving which also results in flux in the understanding of Open Source in those domains.

5 Given the subject matter, this is probably best reflected in the related Wikipedia articles, especially http://en.wikipedia.org/wiki/Open-source_software and http://en.wikipedia.org/wiki/Open_source

ICT4D: Information and Communication Technologies (ICT) for Development – in short: The use of ICT for the assistance of disadvantaged populations. The field is varied and can concern different areas ranging from the facilitation of educational aspects (e.g. through Internet access), civic issues such as giving marginalized people voices through social media up to improving agriculture through sensors or weather forecasting.

2 INTRODUCTION

"[...] we need to see the hackerspace not just as a place that amortizes the cost of a laser cutter and a 3D printer across hundreds of people. It is a place where people are experimenting with new ideas about the relationships amongst corporations, designers, and consumers. It is from this perspective that we approach questions of expertise, materiality, and criticality – topics which increasingly also define the relationship between HCI as a discipline and other cultural groups with which HCI interacts."
(Lindtner et al., 2014)

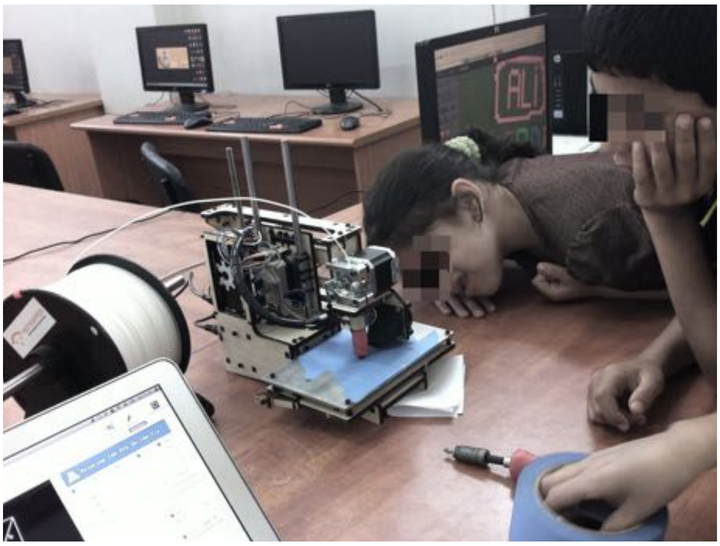

Figure 1: A little Palestinian refugee girl curiously examines a 3D printer.

Access to digital fabrication technologies like 3D printers has become a more and more widespread in recent years. It is no longer limited to professional organizations but also to smaller businesses and especially to end users and hobbyist *Maker* communities – digital fabrication technologies become increasingly democratized. Bottom-up communities and associated, dedicated Makerspaces or Fabrication Laboratories (Fab Labs) are flourishing world-wide from downtown Boston to rural, developing countries. Those socio-technical phenomena represent an evolving field whose values, challenges, practices and socio-cultural significance are emerging rapidly and in a huge variety of domains, which make them a fascinating field of research.

Human Computer Interaction (HCI) has also increasingly gained interest in the field of Making: New and more appropriate interfaces and tools for digital fabrication have to be developed, emerging non-professional design practices to be understood and supported, opportunities for Computer Supported Collaborative Learning (CSCL) to be explored, new paths for innovation to be studied, the machines, the software and, crucially, the human to be integrated better, just to name a few of the more obvious aspects.

Over the last one and a half years or so, Making has also gained some traction in our HCI research group at the University of Siegen, Germany. We acquired 3D printers, a small community of Makers has formed itself and first investigations and studies into Making and digital fabrication have been conducted. We concerned ourselves with such aspects as how to make the – rather complex – technologies more sociable and to facilitate appropriation, how and why communities form around Making but also how to improve current interfaces and tools for 3D modeling and 3D printing. This research has been conducted with academic and hobbyist groups of makers (Ludwig et al., 2014a) as well as in educational settings with children regarding 3D printing (von Rekowski et al., 2014) or sewing e-textiles (Weibert et al., 2014).

Given our research group's focus on practice (cf. Wulf et al., 2011, for more detail), a further logical development was the currently ongoing founding of Fab Lab Siegen[1], coordinated by myself – in this thesis, I will also touch on the project briefly.

However, our efforts in the field of Making in educational and ICT4D settings, are central to my thesis: Here, we do not only focus on western backgrounds but also on marginalized, poorer settings with Palestinian refugees in the West Bank, addressing the potential of Making for ICT4D. As per our research tradition, those efforts are very much based on inquiries into actual *in situ* practice, e.g. by utilizing ethnographic methods such as observations and interviews as well as (participatory) action research (Kock, 2007) as a frame for our work. Having spent five weeks in the field in the West Bank and helped to spearhead those maker-related efforts, the report and analysis of the *Making@Palestine* project is the core of my thesis.

2.1 RESEARCH AGENDA

When we set out to bring Maker related work into our HCI research and practice, we had a grounded notion that both areas might benefit

1 www.fablab-siegen.de

each other based on literature as well as previous explorations into digital fabrication. The latter included visiting Fab Labs and Makerspaces as well as trying out, testing digital fabrication technologies, mainly 3D printing, as well as our own attempts at Maker projects[2]. However, the field is huge, rapidly evolving and highly interdisciplinary. So, when I started to frame and plan this thesis, I needed to narrow the scope of my work down to a manageable level within the given time frame and resources. In the following, I will detail my reasoning behind this focusing process leading up to my research agenda. It is important to note that I will be relatively brief at this point – more details will follow in the State of the Art (3):

From here on out, blue Numbers like (2) will reference chapters, sections and subsections. They are clickable and link to the respective section.

2.1.1 *Basic reasoning*

First of all, there seems to be a growing interest in Making as indicated by more and more Makerspaces around the world, a rising number of scientific publications or even – anecdotally – the fact that you can buy 3D printers for the first time ever at mass market vendors such as Tchibo[3] for the Christmas trade 2014/15. There are many such puzzle pieces which, in total, seem to warrant the assumption that Making and digital fabrication are areas with potentially interesting and relevant implications through a variety of (research) lenses such as economy, sociology, innovation, societal empowerment. Especially HCI potentially has an important role to play in Making which revolves around social issues (such as the underlying "Maker Culture") that are tightly interwoven with novel technologies relating to digital fabrication. Within this weave, novel practices of appropriation, of empowerment and the interconnection between the physical and the digital are emerging – intersections HCI is, pretty much by definition, predestined to research in depth.

Making (especially with a focus on digital fabrication) seems to fit well with ICT4D through an underpinning focus of open source / open hardware, democratization of (high-)tech production, sharing and giving new means of innovation and fabrication to everyone – indeed, we can see application examples in such projects as a successful Oxfam-led call for designing 3D-printable solutions for hand sanitation in disease-ridden areas (Gardner, 2014) or globally distributed DIY prosthetic projects (Krassenstein, 2014). Hence, an ICT4D-related field of study to start a HCI-motivated inquiry into Making and digital fabrication seemed apt. Given a research tradition grounded in case studies, in-depth ethnographic work and situated understand-

2 One example would be my "HackDock", a DIY docking station for notebook computers, see http://www.oliverstickel.de/hack-dock/.

3 A German chain of coffee and mixed goods stores.

ing of HCI issues, it was my aim to take the very broad reasoning and assumptions from the previous section and to find an appropriate case to research in-depth. I believe I found such a case in our research project come_IN. I will detail the project in 3.5, but to give a brief overview: It is an international network of open, integrational, bottom-up computer clubs for children (and adults) in which they can learn, play, express, empower an educate themselves by way of collaboratively working on ICT projects.

2.1.2 *Synthesis and research agenda*

Even through the rather brief descriptions up to this point, it should be obvious that there are conceptual similarities between come_IN, Fab Labs and the Maker culture. Come_IN by design touches on informal, bottom-up learning processes moderated through ICT towards empowering a marginalized people. Fab Labs and the Maker movement aim at broader empowerment in the sense of giving everybody access to means of high-tech production to facilitate innovation as well as socio-economic change towards a more peer-based production (as opposed to mass-production). To this end, Fab Labs are also always understood as places for informal and community-based learning[4]. Those conceptual similarities lead up to the following research question:

Can Making (especially based on digital fabrication) within the context of come_IN in Palestine help in reaching the project's goal of socio-cultural empowerment through constructionist, informal learning processes?

Given this research question as well as my background and interest in the development and / or improvement in socio-technical systems, necessary subquestions from an HCI perspective are also:

How does the ICT (such as the machines for digital fabrication themselves) have to be designed?

How can the ICT best be introduced and how can appropriation processes best be scaffolded?

Those questions are relatively broad and open, but as of now, we have never worked with digital fabrication in the specific settings of our Palestinian come_IN clubs and while there is quite a bit of related work around Making as an educational strategy in general (more in the State of the Art), there is a gap in published research in the specific area of Making with children in marginalized, sensitive and special

4 See the Fab Charter at http://fab.cba.mit.edu/about/charter/

settings such as Palestinian refugee camps. This, to my estimation, makes an open, explorative and careful approach sensible.

2.2 STRUCTURE

To try and answer my research questions, I will first give an overview about the State of the Art of Making and HCI (3) as well as the relevant pertaining areas such as work on computer clubs for children and the foundations in CSCL. Subsequently, I will go more in depth in the core empirical part, namely the case study *Making@Palestine*, our previously mentioned efforts in the West Bank. For this thesis, I will focus on two aspects of this study which have emerged as central for HCI and Making during the analysis:

1. The benefits and successes of 3D printing in marginalized ICT4D-settings with children. The broad and overarching theme here was *self expression* (6).
2. The caveats and problems we were able to uncover. Most of them relate to issues which can potentially be solved through applied HCI, such as usability / complexity problems in the tools or issues with collaboration support (7).

I have to stress the fact that we worked qualitatively and lead *by* the field *in* the field which, through iterations of research, coding and analysis, led up to those core themes. This approach is inspired by Grounded Theory (Strauss and Corbin, 2008), even if I do not claim to have built a comprehensive theory. I will detail the methods in more depth in 5.

Subsequently, I will discuss the empirical part of my thesis (8) with a focus on the research questions before looking towards current and future work in an outlook (9) in which will also detail Fab Lab Siegen (9.1) as an infrastructure for future investigations into Making from an HCI perspective and and the "Resha" laser cutter as a Fab Lab Siegen project example (9.2) which is intended to expand our focus to encompass more than just 3D printing. Finally, I will close my thesis with some personal words (10).

3 STATE OF THE ART

To lay the foundation for my empirical work, I broadly clustered and built up the related work into the following aspects: HCI (3.1), Making (3.2), connections of HCI and Making (3.3), ICT4D (3.4) and a more specific section on the come_IN research project (3.5):

3.1 POSITIONING WITHIN THE HCI COMMUNITY

Human Computer Interaction or HCI concerns itself with the study of people and interactive computer systems, specifically their interactions, making it a highly interdisciplinary field concerning (among others) disciplines such as computer science, psychology, sociology or media sciences. Apart from scientific insights and findings, its main goal is to advance interactive systems regarding their interactions with and according to the needs of their users. To this end, concepts such as usability (effectiveness, efficiency and context-specific user satisfaction), see ISO (2010) and UX (short for "user experience" – users' behaviours, attitudes and emotions regarding ICT), see Hassenzahl (2008) are employed. They are also put in process models such as User Centered Design or UCD (cf. Vrendenburg et al., 2005, for a good overview) intended to facilitate the conception, design and implementation of human-centered interactive systems.

3.1.1 *Research traditions and positions*

Historically, HCI it has its main roots in psychology and computer science with Rogers (1984) often cited as the conceptual origin of the discipline. This origin led to a stream of quantitatively motivated HCI which attempted (and still does attempt) to understand and formalize HCI issues such as menu navigation through models based on psychological experiments – a prominent example relating to keyboard input times being GOMS (John and Kieras, 1996). A – to me – very nicely written reference for more detail on this stance towards HCI is Raskin (2000).

However, there is also an increasingly growing stream of researchers within the HCI community that views traditional, theory-laden, more deductive and experimental approaches as insufficient for many HCI issues. They argue that many socio-technical issues are highly subjective, inextricably embedded in a context and interrelated to complex communal, societal and other structures, values and practices – this position necessitates deeper, situated and qualitative approaches to HCI. An excellent overview about this position and related methods can be found in Adams et al. (2008). On a related note, it should also be mentioned that certain streams within the more situated HCI, especially Participatory Design (PD) have always been in a field of tension between leftist empowerment ideals and work / economic context , see e.g. Kraft and Bansler (1994); Ehn (2008)

For the purpose of this thesis, it is important to note that my work is grounded in the latter approach and I am, in turn, embedded in a HCI research group which places great emphasis on contextual, qualitative and situated understanding of all things HCI – the basic positions we work with are best summed up in Wulf et al. (2011): In essence, it is about understanding and engaging with given practices and structures to ground the development of ICT which then is (co-) developed and tested iteratively together with actual users over time.

3.1.2 *Communities and collaboration*

Given the aforementioned focus on practices and context, HCI offers powerful perspectives to understand the formation and behavior of communities, especially communities of practice or CoP (Wenger, 1998) which are understood as groups of people who share a certain tasks, e.g. through their profession and in which learning processes happen. Etienne Wenger, who coined the term, has phrased it concisely: "Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly." (Wenger, 2009). CoP are constituted by a *common domain* in which the members are interested, a actual *community structure*, meaning the members engage (e.g. by discussing or working on joint projects) and *practice*, meaning simply being interested in the same area is not enough – members actually have to do things, develop and share tools and experiences (Wenger, 2009). How to facilitate knowledge sharing and collaboration in such communities is also a concern in HCI (cf. e.g. Hoadley and Kilner, 2005) as well as Computer Supported Cooperative Work (CSCW) which has long been concerned with such facilitations (cf. Schmidt, 2009; Grudin, 1994).

Related to communal aspects is the concept of Boundary Objects, defined by Star and Griesemer (1989) as:

> "[. . .] objects which are both plastic enough to adapt to local needs and constraints of the several parties employing

> them, yet robust enough to maintain a common identity across sites. [...] They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation"

So, in essence, they are artifacts which help with the facilitation of communication and understanding between different communities. Lee (2007) expanded on the concept by proposing "Boundary negotiating objects", suggesting that such objects might also help to actually *form* (new) communities, not just with the communication between existing ones.

3.1.3 *CSCL and Constructionism*

There is a general trend in education away from teacher-focused to learner-centric approaches – see CACM special issue on this topic (Cohen (1996), especially Norman and Spohrer (1996). HCI, especially motivated by the discipline of Computer Supported Collaborative Learning or CSCL (Stahl et al., 2006) has long been concerned with how to support such approaches with ICT, e.g. through multi-touch systems or video-game inspired approaches This is witnessed by the amount of engagement at influential HCI venues such as CHI[1], see e.g. Tse et al. (2011).

For the intents and purposes of this thesis, the central theory of (Computer Supported Collaborative) Learning we will be concerning ourselves with is *Constructionism* (Harel and Papert, 1991): Seymour Papert's and Idit Harel's understanding of experiential learning holds that learning does not happen through instruction-based teaching but rather through the construction of individual mental models in the learner – a process facilitated through the actual construction of individually meaningful artifacts.

Constructionism has its roots in *Constructivism*, a learning theory pioneered by Jean Piaget (cf. Murray et al., 1979, for a condensed overview about and more references on Piaget's extensive work). It essentially holds that we learn through constantly seeking meaning in the world and individually constructing knowledge to fulfill this search. Edith Ackermann captures Constructivism concisely:

"[...] knowledge and the world are both construed and interpreted through action, and mediated through symbol use. Each gains existence and form through the construction of the other. Knowledge, to a constructivist, is not a commodity to be transmitted - delivered at

1 http://www.chi2011.org/

one end, encoded, retained, and re-applied at the other – but an experience to be actively built, both individually and collectively" (Ackermann, 2004).

Constructionism and Constructivism are quite related: In essence, Constructionism details situations and processes in which constructivist learning happens exceptionally well – namely the building and sharing of artifacts. For more detail on this, I would like to – again – refer to Ackermann (2001) who concerns herself with the minute differences (and connections) between both schools. However, to give an example for the specifics covered by Constructionism: ICT is viewed as the most potent tool to facilitate learning: There are long-running and very successful related projects such as Scratch (Resnick et al., 2009) centering on constructionist approaches to programming.

3.1.4 *Appropriation*

If we talk about HCI from a qualitative, situated perspective (especially when working our way towards Making and DIY), the concept of appropriation (Pipek, 2005) is also relevant: It is the discovery and sense-making of a specific artifact such as an ICT-system *while using it*. It is related to such work as Dourish (2003) which is about how users fit ICT in their practices by adoption and adaption. Appropriation entails things such as customization of technology but goes deeper than that in that it can also relate to drastic changes in practice and ways of changing the system in ways unintended and not anticipated by its designer. Again, community aspects are relevant since appropriation is often associated with social networks of users, sharing and exchange (e.g. Gantt and Nardi, 1992; Pipek and Kahler, 2006).

3.2 MAKING

In the following, I will expand on my definition of Making which preceded this thesis with a focus on the literature around Making which is most relevant to our case study, specifically:

Making, Do-It-Yourself (DIY) and hacking, backed by digital fabrication technologies have seen a significant uprise in recent years. This is facilitated through advancements in technological capabilities for sharing and collaboration (Tanenbaum et al., 2013) and, of course, through cheaper and more approachable (consumer-accessible[2]) digital fabrication machinery.

The Printrbot Simple we use for our fieldwork in Palestine costs 349 USD as a kit, just to give an example. See `printrbot.com`

2 The fact that there even *are* consumer-focused 3D printers is a relatively new phenomenon – machines like the "New Matter" 3D printer increasingly emphasize consumer values like integration in the home. See `http://www.newmatter.com`

Those developments spark the formation of an increasing number of related communities, which also build physical spaces to pursue Making: The number of Fabrication Laboratories (Fab Labs), Hacker- or Makerspaces (Gershenfeld, 2005) is steadily growing[3]. This *Maker movement* is a world-wide phenomenon and finds applications for its DIY-spirit in a huge variety of projects which range from the manufacturing of personal electronic devices (Mellis and Buechley, 2012) through the deployment of digital fabrication technologies in educational settings with children (Blikstein, 2013) up to Fab Labs as venues for bottom-up efforts in ICT for Development or ICT4D (Krassenstein, 2014; Mikhak et al., 2002). For a more localized account of Making and bottom-up culture in the surroundings of (my) University of Siegen see Stickel et al. (2014a).

Two of the most visible organs of the Maker movement are *MAKE*-magazine[4] and a series of global, frequent conferences-come-faires-come-happenings called *MakerFaires*[5]. People associating themselves with the maker movement often call themselves "Makers". The Maker culture is related in its values to the much older Hacker movement (Thomas, 2002) but the latter one is more associated with software and computers and less with a substantial variety of physical production as employed by *Makers*.

3.2.1 *Counterculture and vision*

Obviously, DIY itself is not new – people have been making things on their own since the dawn of humanity. In fact, for a long time, activities such as sewing clothes or fixing tools have been simple necessities of life. Modern society has done away with most of those necessities, instead emphasizing consumption and mass production (Piore and Sabel, 1984). The recent Maker movement often has aspects of a counterculture to those developments, emphasizing openness, empowerment and *in situ* access to production (Tanenbaum et al., 2013; Moilanen and Vadén, 2012).

As a sidenote: Such thoughts are related to other movements like Punk (one's own music, labels, clothing,. . .) or Transition Town (re-appropriation of urban spaces).

Evidence for the values mentioned above values cannot only be found in the maker communities themselves but also in products such as open hardware platforms like Arduino[6] and in new financing models like crowdfunding[7] to bring products to market in a bottom-up way. The Maker movement is socio-technical in nature in that it utilizes and develops technologies but also places great value in doing so in open, democratic community spaces such as Fab Labs or

Arduino is a hugely popular, cheap and beginner-friendly, freely programmable, micro-controller platform that can be used to make projects ranging from LED matrices up to DIY robots.

3 See also http://fablabs.io for a global overview
4 http://makezine.com/
5 http://makerfaire.com/
6 www.arduino.cc
7 Such as www.indiegogo.com

Makerspaces and emphasizes values such as sharing, learning and teaching, playful and collaborative exploration, mutual support and socio-economic change (Hatch, 2013).

Based on such lines of thought, digital fabrication and Making are even hailed as the next stage in the digital revolution (Gershenfeld, 2012b), opening up the production of physical goods in a similar fashion as the Personal Computer did for the digital domain and potentially disrupting existing socio-economic patterns (Troxler, 2013).

3.2.2 *Economic aspects*

Despite the visions described above, concrete economic aspects are arguably the areas where the Maker movement is least developed (Menichinelli, 2011). There are many opinions and predictions relating to economic disruption through digital fabrication, but setting aside the long-term vision of the Star Trek inspired replicator in every home (Gershenfeld, 2005) and concentrating on the more graspable future, there is not much work on actual business models and sustainability for Fab Labs and Making – a notable exception being Troxler and Schweikert (2010) who studied business ideas of Fab Labs worldwide and develop economically framed guideposts relating to openness, interdisciplinary collaboration, effectiveness and transferability, all focused on value propositions centered on innovation. In a less concrete sense, there seems to be economic potential in bringing together local industry with maker communities in order to facilitate machine sharing, collaboration and co-innovation (cf. Lindtner et al., 2014) – this notion and the corresponding ideas about distributed innovation and and end users as innovators essentially go back to Eric von Hippel (1995).

In any case, it seems safe to assume that digital fabrication and Making will have an impact in multiple disciplines in the foreseeable future (even if the scope and the actual form are less clear) – however, our concern as HCI researchers obviously centers around Human Computer Interaction which is why the next sections will try to bring together HCI and Making:

3.3 HCI AND MAKING

HCI has always been a discipline interested researching and / or producing disruptive and innovative technologies and understanding their relation to society and / or the individual (Lindtner et al., 2014). This is why we also see increasing interest in Making in HCI communities, conferences and journals: There have, for example, been investigations into bringing together DIY electronics with other crafts (e.g. Buechley and Perner-Wilson, 2012) or even into DIY biology (Kuznetsov et al., 2012). Based on such interest, our own research group has been working in Maker related settings for the last years: Examples are ICT4D work with refugee children (Aal et al., 2014), expanding this into 3D printing (von Rekowski et al., 2014), inquiries into the appropriation of digital fabrication in academic communities (Ludwig et al., 2014a), working with e-textiles (Weibert et al., 2014) or tying Maker-type projects into the curriculum of our HCI Master's program at our home university where we are also currently founding a Fab Lab under my initiative.

In a more macro sense, Kuznetsov and Paulos (2010b) look at the "Rise of the Expert Amateur" and argue for more engagement between HCI practitioners and DIY expert amateurs while Lindtner et al. (2014) make a strong case for the relevance of Maker practices and physical Maker-sites for innovation and pose that HCI has a key position for Making:

> "We argue that HCI is positioned to provide critical reflection, paired with a sensibility for materials, tools and design methods" (Lindtner et al., 2014).

I agree with this sentiment and in the following sections, I will try to take on aspects of HCI and bring them together with Making:

3.3.1 *CSCL / Learning*

Digital fabrication and Making offer potentially powerful avenues for Constructionism in that they interconnect the physical and digital realms, offering new opportunities for knowledge sharing, collaboration and global coordination as well as world-wide awareness of other maker efforts. This notion is also at the core of the Fab Lab movement (Gershenfeld, 2005) and there have been many successful educational based on constructionist approaches, cf. Blikstein (2013) for an extended overview – or, to let Papert himself make the point:

> "The simplest definition of constructionism evokes the idea of learning-by-making [...]" (Papert et al., 1991).

Furthermore, Makers are essentially amateur designers and producers. Design research and practice as well as research through design and innovative mental approaches to think about design such as Design Thinking (Brown, 2008) sit, of course, at the very heart of HCI (Zimmerman et al., 2007) and there is already a wide body of work on how to bring such aspects together with education (cf. e.g. Hauser et al., 2013; Lugmayr, 2011).

3.3.2 *Appropriation*

It has to be noted that current hard- and software for digital fabrication usually are either highly professional and complex or still quite experimental and technical (cf. Willis and Gross, 2011). Hence, the available tools and interfaces are not optimal especially for learners. HCI research has to play a highly relevant role in facilitating the appropriation of Maker technologies by working towards better interfaces as well as tighter integration of software, hardware and the human element. We also found indications for such problems in our own work, related to such issues as 3D printers being perceived as "black boxes" by many (especially novice) users and lacks of feedback mechanisms (Ludwig et al., 2014a).

3.3.3 *Community aspects*

Maker communities are usually tied to a specific Makerspace or Fab Lab but there is also a significant element of globality which condenses in collaborative international projects, an ever-increasing number of global maker conferences and gatherings as well as through knowledge sharing and communication via ICT (Tanenbaum et al., 2013; Kuznetsov and Paulos, 2010b) which relates to the understanding and the facilitation of communities through HCI.

Furthermore, communities of Makers often have certain entrance hurdles for newcomers, be it through a preconception as "nerdy", domain specific knowledge and vocabulary or the complexity of the machines (cf. Ludwig et al., 2014a), indicating that a HCI-motivated lens, especially on how to scaffold appropriation infrastructures might be relevant. Furthermore, *Ludwig2014b* indicated that understanding and treating Fab Labs and Makerspaces as boundary (negotiating) objects might help alleviate such issues.

3.4 ICT4D

Another highly relevant aspect for an overview about the related work in regards to come_IN at Palestine is ICT4D: Making offers significant potential for developmental aid, empowerment and help in developmental settings (Mikhak et al., 2002). Projects such as DIY prosthesis, which are orders of magnitude cheaper and can be manufactured by amateurs in the field (Krassenstein, 2014) are already being deployed. Another example would be projects about hygiene and 3D printable tools to support it in disease-ridden regions (Gardner, 2014). There is also a certain amount of work going on that is not actively being published on mass-media, let alone scientific channels

– for example, in the field, we had personal contact with a group trying to work with DIY prostheses in war regions in the Middle East. They quite literally carried a relatively light 3D printer and consumable material on their shoulders over national boarders on foot to help and train in situ.

There has been increasing interest in development issues in HCI in recent years (Ho et al., 2009) and there are arguments for this interest to be expanded to Making in order to develop better, affordable, human centered tools and machines (von Rekowski et al., 2014; Willis and Gross, 2011). Doing this with situated sensibility for issues such as illiteracy, vastly different ICT infrastructure, etc. is crucial for the advancement of Making in ICT4D which is why HCI offers a powerful perspective for this integration.

Last but far from least, ICT4D aspects are connected to teaching and learning in that bottom-up constructionist education, empowerment via Making and digital fabrication can help bridge the digital divide prevalent in development countries: This divide can be understood as "the troubling gap between those who use computers and the internet and those who do not" (Mehra et al., 2004) and is viewed as a big problem in ICT4D in general, specifically in the Palestinian refugee setting (Aal et al., 2014). The connection towards constructionist, bottom-up approaches as a potential remedy has been made by Kafai et al. (2009); Aal et al. (2014) and especially Mikhak et al. (2002) also explicitly expand this notion towards Fab Labs.

3.5 come_IN

Over the last decade and within the research project come_IN, our research group has built a network of computer clubs for children and adults with different cultural and ethnic backgrounds where they can meet, work, play, learn and collaborate as well as express themselves through different projects based on Information and Communication Technology (ICT), see e.g. Stevens et al. (2005); Weibert and Schubert (2010); Schubert et al. (2011). The network consists of multiple clubs in Germany as well as two clubs in Palestine, located in refugee camps in the West Bank (see fig. 2).

All come_IN clubs are fundamentally based on a constructionist understanding of learning. They focus on education, bridging the digital divide as well as on integration. Participants gather at the come_IN clubs voluntarily, usually once a week, for joint sessions and projects which are usually related in a meaningful way to their individual situation, values or experiences. Up until mid-2014, the ICT used in the come_IN clubhouses has focused mainly on completely digital aspects, e.g. constructionist approaches to programming such as Scratch or multimedia projects (cf Weibert and Schubert, 2010). Recently, there has been a push towards working on expanding the clubs into the physical domain and its combination with virtual aspects, embracing Making. In the following sections, I will give a brief overview about come_IN, the pilot projects in Making and tinkering in the clubs as well as expand on goals and discussion points for the next steps on bringing come_IN towards more comprehensive social-physical-digital Maker environments.

Figure 2: Come_IN Clubs in Germany (l) and Palestine (r)

3.5.1 *Background*

Come_IN is based on the computer clubhouse project in the United States (Kafai et al., 2009). This project has sparked a global network of such clubs which are all centered around constructionist, collaborative learning via ICT for children, volunteers and sometimes parents as well.

Come_IN expands the computer clubhouse model in that it also includes aspects of ICT4D through aiming at integration (cf. Stevens et al., 2005; Schubert et al., 2011): Our clubs mainly target areas with a significant migrant population where socio-cultural integration is a problem. In Germany, this e.g. relates to the German-Turkish community, which is still confronted with disparate opportunities and education. In our Palestinian clubs, issues are even more manifold, ranging from the regional socio-political problems, conflicts and instabilities over gender issues and inequalities up to the marginalized state of the Palestinian refugees in their own society. An in-depth look at this complexity can be found in Aal et al. (2014) and I will also describe it in some depth in my introduction to the field and our study (4).

Furthermore, the come_IN approach can be described as grassroots-oriented: Each club is established in a bottom-up fashion together with local actors. Over the years, a successful model emerged which consists of coupling the clubs with institutions like elementary schools in Germany or social centers in refugee camps in Palestine, which help to provide continuity, space and situatedness. Collaboration with a local university has also proved to be very valuable – it can provide (student) volunteers to tutor the usually weekly club sessions, bring in innovation in the form of new ICT or project ideas, outside perspective as well as build up meaningful collaboration between children, adults, parents and students / researchers. We detail these structures in Aal et al. (2014).

Multi-medial self-expression and storytelling via ICT are also important aspects of all come_IN clubs (Weibert and Schubert, 2010) – see also Sawhney (2009) for a study on the power of such approaches for marginalized populations.

3.5.2 *Making in come_IN*

Until recently, come_IN focused its use of ICT mainly towards primarily digital technologies, e.g. Scratch (Resnick et al., 2009; Schubert et al., 2011, the former more generally, the latter specific to come_IN), an educational visual programming environment utilized to create digital artifacts like games or animations which is deeply rooted in constructionist and computer supported collaborative learning tradition. However, with the growing proliferation of new forms of rapid prototyping and manufacturing technologies which increasingly blur the lines between physical and digital, new opportunities for come_IN arise: Those technologies as well as the related Maker culture can spark playful engagement, disrupt the traditional role of the end user as consumer, help form new communities of practice and generate meaningful socio-technical artifacts spanning the digital-physical divide (Tanenbaum et al., 2013). Up until now, within come_IN, there have been two main explorations into opportunities afforded by tinkering and Making:

3.5.2.1 *Tangible e-textiles*

This research was focused on exploring Arduino-based programming as well as children's motivations to make and use e-textiles within the come_IN clubs. As my colleagues put it:

> "[our] contribution is to present a study [. . .] which demonstrates that e-textiles promote children's computational literacy, while at the same time allowing them to construct flexible gender identities as makers." (Weibert et al., 2014).

One of the key findings here is that while at the start, project and making decisions of the children were informed by traditional gender roles, this changed over the course of their individual projects when the lines between "feminine" craft and aesthetics and "masculine" technical building blurred more and more. For come_IN, those insights will also help to hone the research lens on future work in Palestine where traditional gender roles are fixed and lived quite rigorously with negative impacts on expression and integration.

3.5.2.2 *Playful 3d-printing and -modeling*

In one of the German clubs, my colleagues started to explore the video game Minecraft as a playful and engaging way to introduce children to digital fabrication and to explore the role and implications of additive manufacturing in education as well as to work towards designing appropriate tools to support this goal.

Recently, we also expanded this line of work into our Palestinian clubs: Dominik Hornung and myself went into the field for five weeks and worked with Palestinian children in the two clubs in the West Bank on 3D modeling and printing. Some first findings have been briefly described in von Rekowski et al. (2014). However, the next chapters represent more in-depth looks at our field study, focused on the potentials and benefits of digital fabrication for the self-expression of marginalized children (see 6) as well as its problems (see 7).

3.6 SUMMARY

To ground this research question, I have summed up and referenced the relevant related work in chapter 3: First, I have introduced HCI, specifically its more situated, qualitative branch in which I fundamentally position my research (3.1). I elaborated on central aspects for my research within HCI (such as Appropriation) but also expanding onto neighboring disciplines such as CSCL (with Constructionism being the central concept pertaining to my work). I then introduced Making as the second central pillar for my SOTA (3.2). Here, I attempted to elaborate on the Maker culture's core values, contributions and issues centering around aspects such as (bottom-up) counterculture or economic issues. Based on the previous sections, I synthesized HCI and Making (3.3) and it became clear that there are many intersections – for example the great need for better appropriation support in Making or the importance of (Maker) communities (of practice) and their ICT support. Following up, I briefly detailed ICT4D (3.4) before introducing come_IN (3.5).

I believe this State of the Art is sufficient to ground the research questions I put forth in section 2.1:

Can Making (especially based on digital fabrication) within the context of come_IN in Palestine help in reaching the project's goal of socio-cultural empowerment through constructionist, informal learning processes?

As well as the two subquestions:

How does the ICT (such as the machines for digital fabrication themselves) have to be designed?

How can the ICT best be introduced and how can appropriation processes best be scaffolded?

Hence, without further ado, I would like to introduce my / our our work towards answering those questions during the next chapters.

From here on out, I will frequently be using "we" instead of "I" when I refer to the field study which, after all, was carried out collaboratively.

Part II

CASE STUDY – MAKING AT PALESTINE

The Project *Making@Palestine* is an effort to bring Making by way of digital fabrication to our Palestinian come_IN clubs: A colleague and myself spent five weeks in the West Bank, working with children on 3D printing and ethnographically accompanying the project. Since our return, we have been busy analyzing our data and continuing our contact and our studies remotely. In this chapter, I report on our fieldwork with a focus on two central emergent aspects: The beneficial aspects and chances of Making, specifically 3D modeling and printing in the come_IN setting which broadly cluster under "self-expression" as well as the caveats which mainly relate to socio-technical problems with the tools.

4 FIELD OF RESEARCH

The work described in this chapter has been published regarding some aspects in Aal et al. (2014); Stickel et al. (2014b).

This section is intended to give an introduction to the field of our study and its broader context. I believe this is necessary because, even if, for the duration of our study, we acted in the relatively localized come_IN clubs, one should never forget that those clubs are embedded in a very complex weave: The refugee camps, Palestine and the Middle East in general are intricate on a Gordian level which of course also has implications for the more micro-level of the clubs. Furthermore, a glimpse into society and life in Palestine might help the reader to form a better understanding of some of our empirical results, especially those relating to the telling of stories – which, in the given context often relate to socio-political issues. However, I want to stress that I will not and cannot deliver a comprehensive overview about the field – this section should be understood as a brief and non-political introduction.

4.1 PALESTINE AND ITS REFUGEE CAMPS

Figure 3: Impressions from al-Am'ari refugee camp.

During the 1948 Arab-Israeli war, many Palestinians were expelled or fled from their homes in what is now part of Israel, leading to the establishment of refugee camps in the Palestinian territories and surrounding countries (e.g. Jordan). Originally intended to be short-term camps, they still exist today and face unsustainably growing population, rickety and makeshift infrastructure, marginalization and instable socio-economic structures – some camps have 40 % unemployment rates and a population of up to 60 % under the age of 17. This all in a population of more than 10 000 people in an area less than one square kilometer. Those numbers relate to the camp of Jalazone and are estimates by the camp administration, gathered by us in the field. Impressions from the camps can be found in fig. 3.

The camps have a highly sensitive role in Palestinian society in that they symbolize the perceived *"right to return"* to the pre-1948 land. Hence, broad societal integration of the camp population is politically undesirable – yet, at the same time, camp inhabitants are often treated as second class citizens and there is a notable gap in social standing between "regular" Palestinians and inhabitants of the camps (cf. Aal et al. (2014). Education is basic, provided by the UN relief organization (UNRWA) in gender-separated camp schools. Camp administration is facilitated by a "popular committee", an elected body of camp inhabitants.

4.2 COME_IN IN PALESTINE

Figure 4: Come_IN sessions in Palestine

The Israeli-Palestinian conflict is a matter of daily life in the camps, e.g. through raids of the Israeli Defense Forces which can involve violence and in some cases death. Access to ICT and the Internet at home is problematic and further hampered by the fact that especially adults are generally not adept at using such technologies. This is where the come_IN approach comes into play, offering opportunities to bridge this digital divide, in a bottom-up fashion, targeting mainly children (but also including parents, if possible). This also relates to an attempt at bridging the gap between the in-camp and the out-camp society I explained above.

The two come_IN clubs in the West Bank are located in the refugee camps Al-Am'ari and Jalazone which are both located near the city of Ramallah. In both camps, the clubs are located in central community buildings buildings and offer about 12 computer workstations, Internet access, a printer and basic office supplies. Weekly sessions are run by student volunteers from the local university of Birzeit in cooperation with the camp administration (Aal et al., 2014). Scratch and similar playful, constructionist approaches to programming and ICT are the most frequent topics covered in the clubs but aspects like basic HTML or electronics are also covered. Fig. 4 shows scenes from club sessions in Palestine.

4.2.1 *Conflict as a permanent condition*

An aspect from that serves well to illustrate why it is important to explicitly also think about more macro-focused context when doing fieldwork in Palestine is the matter of course with which the conflict is integrated into daily life: Rallies, flags and demonstrations are pretty much omnipresent and represented issues for debate in almost all conversations we had. Sad occurrences like the injuring or even death of protesters as well as escalating raids are frequent. The people adopt: Of course there is a sense of sadness but life goes on and this attitude shows when talking about deeply worrying things like killing of protesters in their mid-twenties – which we sadly had reason to discuss while in the field.

Figure 5: Impressions from Palestine

4.2.2 *Illustrating the impressions*

I attempted to capture some of the field in fig. 5: It shows (left to right) Shuhada street, a ghost street in Hebron which is used as a buffer zone between the Muslim and Jewish population, a mosque and a church next to each other in Bethlehem as a symbol for peaceful co-existence (together with a happy local activist) and us driving through tear gas (the fume in the back) on our way through a clash between Israeli soldiers and Palestinian protesters.

5 METHOD

Given the dynamic and fluctuating nature of Making, we favored a Participatory Action Research (PAR) motivated approach, cf. especially McTaggart (1991) but see also Kock (2007) where we went into the field, implementing change by way of our work with children. Generally speaking, PAR is about researching community structures and effects utilizing the instruments of change and action, yet taking care to participate in the community researched but on the same hand focusing on sound and reasonable research. This also sits well with our general understanding of HCI: All system development should be deeply grounded in practice, necessitating ethnographic fieldwork and – later – iterative development and testing with actual end users (Wulf et al., 2011). The basic approach I described up to this point as well as the data collection, analysis and the process of (co-)developing ICT based on empirical findings I will describe below can also be subsumed under the label of *Grounded Design* that will be coined in Brödner et al. which is currently undergoing review.

Such propositions clash with many research traditions and methods, especially those promoting a level of abstraction, disinterest or naivety by the researcher. Without wanting to discuss those in too much depth at this point, apart from all issues relating to research tradition, I hold that PAR is one of the few honest methodological choices for a study such as ours: We knew that we wanted to implement change / action by introducing 3D printing to our Palestinian clubs and, with limited resources in time and money, but mainly due to the importance of trust and personal contact in sensitive, marginalized refugee settings, it was clear from the beginning that we as researchers had to actively take part in the sessions as tutors, helpers, or whatever would become necessary in the field. Given such a constellation, PAR essentially offers the most truthful and practical choice of methodological framework.

Following those principles and in cooperation with the volunteers, we went into the computer clubs in both refugee camps and moderated the club sessions for the duration of our stay: We introduced and demonstrated 3D-printing and modeling to the children. Those introductions were very basic and delivered verbally and with lots of gestures based on the subject of introduction (i.e. the printer or the software). Given the language barrier and different interpreting skills available, there was no script we followed - instead, we had to react to the situation. However, we always used the basic metaphor of a hot glue gun to explain the 3D printer since those tools are pretty common around the world and serve well to illustrate the principle behind the 3D printing technology we used to almost everybody. We also always printed a demo-object live to illustrate our explanations. For the software introduction, we actively demonstrated the very basic interactions such as moving the camera by clicking and dragging the canvas or building a block by selecting the appropriate tool from the toolbar and placing it in the world by clicking.

Subsequently, we invited the children to work on their own 3D projects. As a 3D modeling tool, we used CubeTeam[1]. It is similar to the video game Minecraft: 3D models are assembled from small cubes in a "Lego"-like fashion. CubeTeam is also collaborative in that multiple actors can work in the same world and even on the same models. Unlike Minecraft, CubeTeam offers a default camera control mode inspired by regular CAD-tools, i.e. by clicking and dragging the canvas instead of ego-perspective "WASD" movement. However, such a mode in which the "players" control the movement of their virtual avatar with the WASD- or Arrow-Keys on their keyboards and look around by moving the mouse can be enabled in CubeTeam as well. Fig. 6 shows CubeTeam on the left and Minecraft on the right.

The children were free to create their own projects with us and the volunteers available for help. Finished projects were then 3D printed by us for the children and given to them to keep. We used a Printrbot Simple 3D printer which we brought with us. The machine is relatively compact, has a build volume of 15x15x15cm, uses PLA (a cheap and easy to handle plastic) as printing material and is easy to fix due to its simple design.

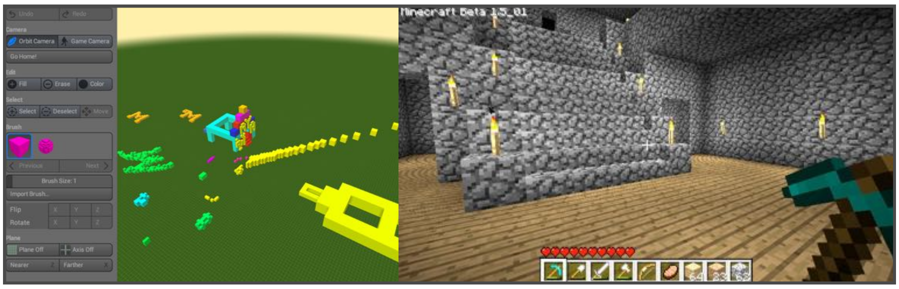

Figure 6: CubeTeam and Minecraft

Our participants were between the ages of 8 and 14 and usually worked in groups of 2-4. In total, we worked with about 20 children for about 12 hours during 6 sessions. The participation was somewhat fluctuating – there is, according to the local coordinator, lack of a culture of attendance / punctuality in the camps which also affects other

1 www.cubteteam.io

institutions like the schools. We observed the sessions, took extensive field notes (about 60 computer-written A4 pages) as well as photos and talked to the children and the volunteers throughout the process which was influenced by the language barrier and only possible when a volunteer had time to translate. Those conversations were ad-hoc and for the most part a bit chaotic due to the often unstructured course of club sessions in the equally chaotic camp environment, the language barrier and the fact that we had to fulfill many roles at the same time (researcher, tutor, 3d printer operator, IT-troubleshooter, ...). Hence, our analysis mainly relates to our observations and field notes and *not* to recorded interviews / transcriptions.

The gathered data was analyzed using Thematic Analysis or TA (Braun and Clarke, 2006). This method which has its origin in qualitative social sciences aims at identifying patterns – *themes* – in qualitative data by way of iteratively searching for initial codes, identifying common themes between codes, reviewing those themes and subsequently naming them. It is very similar to the first steps in Grounded Theory or GT (Strauss and Corbin, 2008) but stops before the grander steps of GT such as theory building. Hence, we deemed TA an appropriate methodological frame for our exploratory research which is not yet suitable for "bigger" theory building. However, for the future, we hope to work towards a more exhaustive GT on HCI issues in Making. TA is sensible as a first step in this process due to its closeness to the first iteration(s) of coding and iterative analysis in GT.

We know of course that GT does not necessarily dictate theory building but if one reads verbal constructs along the lines of "GT inspired..." prevalent in many papers in HCI, it seems, there is a certain lack of clarity afoot. Hence, using the – to our understanding – more clear-cut label of TA seemed appropriate.

The TA itself was deliberately started quickly in the field to build up questions and sharpen the research lens. This was done by daily exchange and discussion of the notes and memos between the field researchers, interspersed by occasional Skype calls with senior researchers at home as to work towards inter-coder reliability. The analysis was finished later at home, also including researchers not immersed in the field. All names were anonymized due to privacy and security concerns and will also be reported anonymized in this thesis.

After our departure, the 3D printing infrastructure was left in place to remotely study the more long-term appropriation and projects by monitoring the Facebook group the Palestinian volunteers use to coordinate their work and share pictures of sessions as well as by e-mail and Skype contact to the volunteers. This thesis draws on both our fieldwork as well as the later remote observations.

In the following sections, I will report in more depth on our results. I try to illustrate our findings with captured moments from our field notes where appropriate to demonstrate the way we took notes. Such illustrations are represented indented and italic, similar to verbal quotes but *without* quotation marks. When I use verbal quotes, I use quotation marks. Such verbal quotes are, however, up to a certain level of interpretation because we relied on local volunteers to translate and since their English skill varied substantially, a lot of the communication, especially with the kids took place in a mixture between gesticulations, more or less consistent translations and signs. Hence, most of the results I report are based on analyses of our field notes, pictures and videos.

6 RESULTS: CHANCES AND BENEFITS IN 3D PRINTING FOR ICT4D

As a general theme, we observed that the playful, collaborative approach was well received by the children and that they were able to create their first printable models quite quickly – sometimes in considerably less than one hour. This is especially remarkable since none of the children ever had anything to do with 3D modeling, let alone 3D printing. In the initial sessions, they quickly started to explore the interface of CubeTeam and figured out its workings on a basic level with on-request help by ourselves and the local volunteers. After some exploration, testing the functions and some random cube placement in the world, the groups usually started a verbal negotiation process about what to build before actually doing so – an example would be a group of three children who, after some discussion, settled on modeling the initials of their names. They then sat in front of one computer with one child taking charge and executing the modeling while the others gave suggestions, pointed at interface or model elements and influenced the executing child.

Figure 7: 3D modeling (l) and printing (r) in Palestine

The three most frequent categories of projects our children choose were: Names or initials, buildings with meaning such as a tower with a Palestinian flag on top (inspired by the flag monument in Ramallah's city center) as well as creatures inspired by fantasy / media or the real world (usually a favorite animal). As an overall theme for what the children created, we chose **self-expression** since all the artifacts had personal meaning or expressed a story / fantasy such as the mosque-inspired building in fig. 8 (top middle) made by Rabi (10) as a "new house for her family".

We generally could observe projects getting more ambitious over time, especially regarding usage of all dimensions: Where they had previously treated the building space more like a 2D canvas, only "brushing" models such as their name with no real complexity in the z-axis, the children started to attempt building more complex structures after some time. Some examples can be found in fig. 8 – the house-like structure (top middle) was built in a later session and includes complexity in all axes while the apple at the bottom left is, essentially, flat. Not only the models themselves but also the negotiation process became more complex and started to include sketches made with pen and paper and more elaborate planning (see fig. 7, left where a sketch can be seen in front of the computer. The following aspects stood out as beneficial for the success of our project:

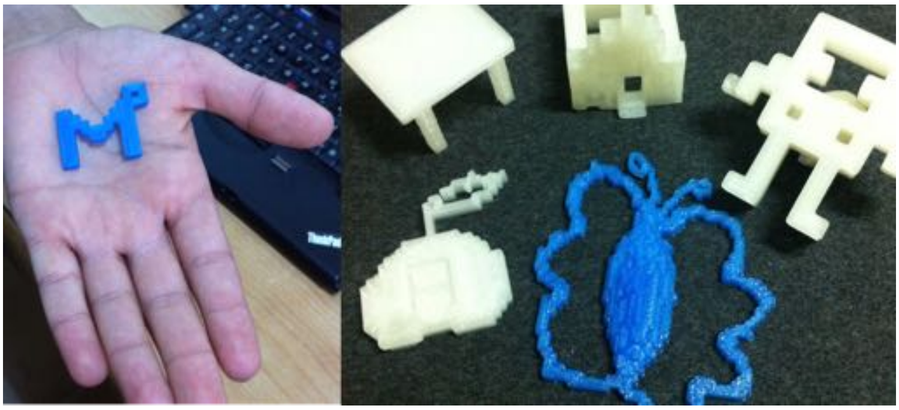

Figure 8: Some sample 3D prints from the field.

6.1 PLAYFULNESS

Playfulness is deeply rooted in Constructionism itself as well as the approach taken by game-inspired tools such as CubeTeam: Freely building things *you want* from Lego-like cubes while zooming around in a virtual world with your friends is *fun* and actually seeing your creations taking shape in a whirring, whizzing machine is even more fun. This sense of ludic exploration also seemed to be inherent in the 3D printer itself, which is not a new insight in itself but it was especially salient in the dire straits of the children's daily lives with limited access to toys and hardly any play areas. Aafia, a student volunteer, emphasized: "you have seen, there is no room to play for the children, they have to play on the streets".

The collaborative and playful tinkering and Making resulted in lots of laughter, joy and beaming faces. One such case would be a group of boys who treated CubeTeam like a video game, running around and building an artifact similar to a game level – a building with a path leading through it and a central chamber with stairs and windows. At the beginning, they had great fun shaping and interacting with the object but later on, when they saw other kids getting their printouts, they became curious and after we printed out their "level", they were amazed, compared it to the digital version onscreen and all three group members wanted a a printout.

6.2 APPROACHABLE COMPLEXITY

> *[...] she [...] is using CubeTeam in a very impressive fashion given that it is just her second time using it [...] This time she is making a face (or rather a whole head) in profile.*
>
> (Field Notes, 3rd session al-Am'ari)

Our children suddenly had the means to create shapes which would have required significant skills, resources and equipment to make by hand. This allowed for new degrees of freedom regarding self expression and storytelling through artifacts – an example can be found in the butterfly depicted in fig. 8: Nahid (she was 9, attended all of our sessions in the camp and was very motivated and curious) who built this model really liked butterflies but was only able to draw them previously which she frequently did. Through digital fabrication, she is now also able to make her own physical butterfly models which she wants to incorporate in her playing. Furthermore, her butterfly now has depth and a shape (e.g. a curved body) which would have been impossible to do by drawing and quite hard if not impossible with other available tools and the skill-set of a young child. Nahid was very happy with what she had achieved and proudly took her creation home. This aspect proved to be especially powerful in the camp setting because of the children's usually limited access to tinkering material such as Lego, coping saws, or other tools – as Wasimah, another volunteer put it: "We now can make things we normally can't".

At this point, however, I have to emphasize that not the whole 3D printing process proved to be approachable and suitable for children – I will report on the caveats in detail later.

6.3 INDIVIDUALIZATION

> *[...] one of the boys was able to make the letter "M" (his name starts with this letter) with an attached eyelet so he can hang it on a bracelet, necklace or keychain. He asks if it can be printed immediately and we confirm [...]*
>
> (Field Notes, 2nd session al-Am'ari)

It is notable that the children quickly realized that they could not only make things but also customize and individualize them. A group of three boys, for example, figured out that they could model eyelets attached to the already finished models of their initials in order to make their creations wearable (see fig. 8, left side) – this discovery happened in both camps we worked independently and each time, it spread quickly by word of mouth as well as over-the-shoulder learning. The children expressed great satisfaction regarding being able to carry around *their* creations on their bodies and some of them showed off their brand-new bracelets or necklaces fashioned from string and the 3D prints in the next sessions.

> *[. . .] most of the kids choose to make letters or write their names in 3d [. . .]*
>
> (Field Notes, 2nd session al-Am'ari)

Nahid, the little girl who likes butterflies, was especially proud, approached us and showed a bracelet with her initials while smiling broadly. Individualization of models through inscriptions or favorite motives became quickly popular, too (also through word of mouth and over-the-shoulder learning). Incidentally, this led the children to discover a basic 3D modeling operation on their own and in an observably intuitive fashion – namely boolean subtraction in order to cut out their names of other solids. Hadil, a girl of 10 discovered this cutting process first and modeled an apple (the process is depickted in fig. 7, left) which she later on decided to individualize it with her name. Notably, all inscriptions were done in Latin letters.

6.4 IMMEDIACY AND PHYSICALITY

> *[...] The same effect as in the last sessions occurs: Everything is more chaotic at the beginning but after the first kid / group of kids makes an actual printable model and we start printing, the kids get big eyes and actually realize that we can MAKE stuff! After that, everything accelerates: The kids seem more motivated and everybody wants to have something printed [...] The motivation and drive gets more and more intense and the club even gets to a sound level resembling quietness [...]*
>
> (Field Notes, 2nd session Jalazone)

We could observe a similar effect in almost every session (always when new children were present): At the beginning when we demonstrated the 3D printer, the children were rather interested but not really fascinated yet. We then told them that they could make things and we could print them right now, right here. However, this did never really sink in until the first kid tentatively and usually a bit nervously showed us her or his model, which should be printed. After we initialized the print and the children saw that what we promised was actually possible and one of their peers was *really Making something*, eyes widened, interest became fascination and efforts to build 3D models were redoubled – a short time later, we usually were buried in models to print. The children surrounded us and the printer, observing the prints – especially if they recognized the model in the printer as their own which heightened the excitement in the room even more.

> *She shows us a bracelet made by her with the help of her parents from which one of her 3D prints is dangling. She looks quite proud and smiles at us.*
>
> (Field Notes, 3rd session Jalazone)

Another central aspect of this theme which also has connections to Individualization is that the children really liked being able to *take their prints home*, to show them to their friends and parents and to explain to them how they had created the artifacts and what they meant to them. Together with further Individualization (e.g. fashioning bracelets) collaboratively with friends and family, this led to *conversations* between children and their parents about what they did in the club. Those conversations could actually revolve around the individual artifacts, unlike with many previous projects, e.g. with Scratch which the children simply could not show to their parents due to the lack of a computer and Internet at home – to say it with Aafia's words: "They do not have Internet and the parents do not know how to use a Computer. It is bad because if we make Scratch projects they [the children] can't show them [the parents]".

6.5 collaboration

As explained, CubeTeam is inherently collaborative in that users can work in the same world and at the same models. Most children expressed curiosity about what their friends did and were able to check on this directly in CubeTeam, which generated a certain awareness and had beneficial effects such as starting the popularity of eyelets described above – however, as already indicated, most of the actual exchange happened by word of mouth and over-the-shoulder learning with the virtual world only providing the initial spark.

Virtual live collaboration on the same model did not happen at all – instead, the children rather changed or expanded groups in real life depending on current interest such as in the case of Ruhi (12) changing groups because he did not want to build names anymore but rather wanted to join a group working on a building-like structure.

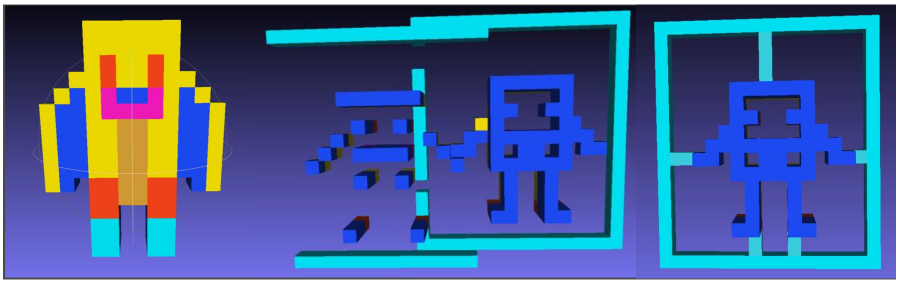

Figure 9: Different Spongebob variations

Notably, Gulshan and Nakia, two girls from different camps figured out how to copy models which led to one child starting a model and another child remixing it according to their tastes and fantasies. Fig. 9 shows variations of such a Spongebob-inspired model. In this case, things even went so far that the initial model was created in one camp by Gulshan and later found, copied and modified in the second camp by Nakia. Her modifications seemed to be experimental in nature and artistically inverted the figure or attached a frame around it.

There were also inter-generational collaborations: The older student volunteers were rather fascinated by the technology, too. Some of them started not just to supervise and help but to actually work together with the children. A very powerful and expressive example of such a project (which was built after we departed) that also serves as testament to the local conditions can be seen in fig. 10 – the 3D model itself was downloaded from the Internet but its coloring and the way it was put together was done in a collaboration between the children and the student volunteers. It was inspired by the 2014 escalation of the Gaza conflict according to a Skype-Interview with the local project coordinator.

Figure 10: 3D print of a rocket on a truck.

6.6 MOTIVATION (TO COME BACK)

> *[...] she tells Zahid (who translates for us) that she dropped an English course she was supposed to take to come to our 3D printing sessions since she is really curious and wants to experiment [. . .]*
>
> (Field Notes, 2nd session al-Am'ari)

All of the themes we described until this point also led up to a more meta theme: The camp children often exhibit "lack of motivation and distracting behavior" (Zahid, local coordinator) and "attend infrequently" (Aafia). The 3D printing project sparked *motivation* to come back for the next sessions, to attempt more challenging models and to learn more which is exemplified by Masun, a boy of 10 or 11 was generally rather unruly, unfocused and did not really do anything but disturb other children during most of his first session. However, after he saw another group of children admiring their own physical creations, Masun suddenly went back to his computer and tried to model his initials. He still needed some tutoring and occasional quieting-down but finally managed to successfully make a printable model (and he came back in the next sessions).

7 RESULTS: PROBLEMS AND LIMITING FACTORS FOR 3D PRINTING IN ICT4D

In the previous chapter, we reported the aspects of Making and 3D printing that seem especially beneficial in ICT4D-settings. However, as we already indicated, we also found some caveats, especially relating to the available tools on hard- as well as software levels. Many of those issues are closely related to HCI, which, as a research and practice discipline, can help alleviate them. After we realized this (based on literature as well as our evolving analysis in the field), we wanted to contribute to this stream of work by taking special care to observe points of error or incident in order to work towards tools for digital fabrication that are more suitable for education of children. Our most notable results were:

7.1 Orientation and camera control

> *[...] generally, they can handle the modeling quite well even if it is their first time using it. The usual problems with adjusting the camera and navigating in 3D space occur frequently.*
>
> (Field Notes, 3rd session al-Am'ari)

The mapping of orientation in 3D space to the intended task seems to be very difficult for children. We repeatedly observed attempts of children placing a building block at locations semi-occluded by other structures. The tasks would have been made easy by moving the camera to a different angle but this usually only happened after multiple failed attempts or through tutor support. To give an example: Hadil, the girl who made the apple, was quite adept wit CubeTeam's interface and knew exactly what she wanted to make. However, she needed continuous help from one of the volunteers (see fig. 7, left) to figure out perspective and camera control.

> *They mostly walk around in the WASD mode and carve the cube from the inside. They seem to be very used to WASD controls and are actually using CubeTeam more to walk and jump through the world (and to joke around a lot) than to really focus and create something specific.*
>
> (Field Notes, 3rd session al-Am'ari)

As a counter-example, the group of boys we described above used the "WASD"-movement mode offered by CubeTeam quite adeptly –

when we asked them, they reported a lot of experience with Ego Shooter video games.

7.2 LACK OF COLLABORATION AND COORDINATION SUPPORT

As indicated above, collaboration proved be a beneficial factor. However, on the tool level, we observed problems with actually supporting negotiation and coordination between the children. One of the central themes was the fact that it is often unclear who "owns" or works on which structure:

Wasil (13) wanted to extend the video-game level-like structure we described previously. However, the original authors did not attend the session which (after figuring out who the authors actually were from memory since there is no way to find this out in CubeTeam) led to uncertainty if the modification would be okay with them.

The only real means for collaboration support in CubeTeam is an single chat channel which did not get used at all by the children. Another factor that came up was mischief – Masun started to randomly place huge amounts of cubes allover the world, including over structures on which other kids currently worked on. This led to frustration, especially by Nahid who was currently working on an intricate model of a human face which got disturbed by the troublemaker – we had to intervene and manually use the undo-function at the boy's computer.

7.3 CONSTRUCTION AND LIMITS OF CURRENT 3D PRINTERS

> *Unfortunately, the model of the apple has some issues so we cannot print it right away but promise that we try it at home and bring it next time. The building Imani made is also not printable since the structure is too weak. We suggest that we modify it a bit so its printable and also try printing it at home. Disappointment ensues.*
>
> (Field Notes, 2nd session al-Am'ari)

The currently prevalent plastic-based FDM 3D printers have certain limitations regarding overhangs, printing in color, resolution or floating structures. Those limitations can be complex, vary from printer to printer and are highly relevant to the outcome of a 3D print. Since the children can not reasonably be expected to know or such those issues quickly, we frequently observed attempts at building structures with problematic elements: An example would be the letter "i" in a model of Nima's (11) name: In the virtual world, it does not matter if the dot of the "i" is not connected to the lower part – it stays where it has been placed, unlike in the physical printout. We usually resolved such issues by explaining the basic problems (often hard to understand for the children) and, in many cases, applying small fixes ourselves before printing.

Color also was problematic – some children understood the limiting fact that we could only print with one color at the same time (e.g. Nahid the girl with the butterfly) while others such as Nakia with her Spongebob-variations tried to use multiple colors which got lost in the printout.

Another related aspect is that many current 3D printers are constructed openly. This resulted in many situations where we had to keep prying fingers away from dangerous parts. Masun in particular was very curious and repeatedly tried to touch the hot end (about 210 deg. Celsius) of our printer despite being told equally often that this would hurt quite a lot, resulting in at least one of us or the volunteers having to keep near the printer at all times.

7.4 usability and ux issues

> *[...] Interface problems also arise frequently – clicks on the wrong buttons or being stuck in a certain mode (such as the selection "pencil") and not finding the way back happen a lot. Focused user tests and re-structuring might be advisable.*
>
> (Field Notes, 2nd session al-Am'ari)

We frequently observed problems with the interface for the 3D modeling where icons and concepts for certain operations were not understood. Random clicking around on the UI until something ensued quite regularly and more advanced functions like options to add helper planes did not get used at all. Furthermore, in some instances, children left the world, usually by accident, and got lost in the tool, sometimes creating a new world containing only them.

Those issues were, however, probably reinforced by the language barrier in our case. The later steps in the 3D printing process were even more problematic: Actually printing something out requires work steps such as calibrating the printer or handling advanced tools such as *Slicer* software[1] with many technical parameters to transform a 3D model into instructions for the 3D printer. Hence, we had to carry out the printing ourselves. In some cases, we tried to explain what we did to some interested children but they quickly lost interest because through the degree of complexity involved and the very technical tools, such attempts turned into lectures which clashed with the constructionist atmosphere of the project.

1 We used Repetier Host with the Slic3r option, see http://repetier.com.

Part III

CLOSING

First, I will recapitulate and discuss the empirical part of my thesis. Subsequently, I will give a longer outlook in which I introduce Fab Lab Siegen as my future field of research as well as the DIY "Resha" laser cutter as an example for the first Fab Lab Siegen project. Finally, I will close the thesis with some personal words.

8 DISCUSSION

To start of with a brief recapitulation and a more meta-oriented discussion: Making@Palestine forms the core empirical part of my thesis and after five weeks in the field and months with ample time for reflection, further literature work, analysis and discussions together with researchers and Makers from all around the world, I believe it is safe to say that we did something worthwhile and were able to gather relevant results to advance the scientific discourse in our areas.

Apart from hopefully delighting and helping a few children, we were able to find out novel aspects: Making as a constructionist, educational tool in marginalized settings seems promising and we were successful in identifying at least some of the aspects which appear to be responsible for this success. Relatedly, we also were able to find problems and extrapolate some design implications for future tools for digital fabrication which I will discuss in the following right after repeating my research questions again as a reminder and as a basis for structuring the discussion. My main question was:

Can Making (especially based on digital fabrication) within the context of come_IN in Palestine help in reaching the project's goal of socio-cultural empowerment through constructionist, informal learning processes?

It was supplemented by two additional sub-questions:

How does the ICT (such as the machines for digital fabrication themselves) have to be designed?

How can the ICT best be introduced and how can appropriation processes best be scaffolded?

8.1 THE GOOD

I believe it is safe to state that 3D printing and, more generally, Digital Fabrication constitute powerful and innovative tools for ICT4D. This relates back to my basic research question (see 2.1) in which I asked myself if Making and digital fabrication can help with come_IN's goal of socio-cultural empowerment through constructionist, informal learning processes. Based on our empirical findings, the answer would be "yes" – yes, we saw constructionist learning processes around playful approaches to 3D printing and 3D modeling and yes, those processes happened along a broad theme of self-expression which most certainly is a form of socio-cultural empowerment in the marginalized refugee camps. Of course, we need to discuss this in more depth which is best done along the lines of the themes we identified as central for the success: *Playfulness*, *Approachable complexity*, *Individualization*, *Immediacy and Physicality* and *Collaboration* as well as *Motivation* on a more abstract level.

Playfulness seems immanent to Making and digital fabrication in general which confirms finding from the literature (cf. Blikstein, 2013; Gershenfeld, 2012a). However, this aspect really shines in ICT4D settings where there is a sore lack of ludic engagement. In such settings, we have seen and showed that an emphasis on playfulness helps to work towards otherwise often lacking continuous participation and motivation. Such motivation was also helped along by *Approachable Complexity*: Despite functional shortcomings when compared to more powerful CAD tools, the choice of a toned-down and especially playful tool like CubeTeam works well in ICT4D settings, encourages exploration, leads to quick and iteratively growing successes and motivates the children. Both themes also have direct implications on how to scaffold the appropriation of ICT for Making in ICT4D-contexts (i.e. my third research question): Ludic aspects need to be emphasized, e.g. through the application of a game-inspired modeling tool and, more generally, through a focus on tinkering, curiosity and exploration instead of top-down instructions or feature-laden, complex and usually less engaging (but more powerful) tools for 3D modeling.

The aspects of *Immediacy and Physicality* may be among the most important and lasting ones: Apart from findings about the general social dynamic of learning 3D modeling and printing (slow start, huge motivational boost through seeing your *own* creations being printed) which might help scaffold future didactic concepts, the most central aspect for ICT4D is: *Taking things home* – when we are talking about ICT4D, we often think of purely digital projects given the fact that everyone of us usually has access to (multiple) computers and the Internet whenever desired. This is not true in settings such as the refugee camps, making storytelling and self-expression transcending the come_IN club hard for our children. Through 3D printing which interconnects the digital with the physical, we were able to break this border in parts, with the printouts taking the role of boundary negotiating artifacts (Lee, 2007). In previous work with older Makers, we found that digital fabrication frequently seems to take on such a role (Ludwig et al., 2014b) which leads us to the speculation that Immediacy and Physicality might generalizable factors influencing the motivation to put work and perseverance in the process of Making as well as to spread the word. To relate this to successfully facilitating appropriation, I would draw the conclusion that a) actually bringing the printer in the field (as opposed to printing later at a university, Fab Lab or other location) and b) encouraging the *taking* of models (instead of collecting them on a shelf in the club or similar) are vital.

Another central theme pertaining to self-expression was *Individualization* through inscriptions or attachment of eyelets to make creations wearable. This also proved to be a significant motivational factor. The aspect of wearability nicely relates and compliments the previous work of our colleagues in Weibert et al. (2014) and other Maker-related contributions such as Kuznetsov and Paulos (2010a) which focus on wearables. Individualization also helped the children to show off and talk about their creations as well as the stories behind them and to engage friends and family members in joint activities such as manufacturing bracelets to attach the 3D prints. This can also be understood as part of an appropriation process – it constitutes engagement with as well as usage and transformation of the created artifacts after manufacturing (which in turn might lead to different approaches and goals when virtually creating the next 3D model).

If we try to look at this theme in a more general sense, we see relations to the Maker movement as sort of an antithesis to mass production and consumption. The value behind creating individual and innovative products through one's own work seems to be highly relevant in a spectrum of settings ranging from our refugee camps up to western settings where where the market relevance of end user innovation has long been announced (von Hippel, 1988) and where we currently see experimentations with related shifts towards a more peer-based idea of production (Moilanen and Vadén, 2013).

Aspects of *Collaboration* are highly relevant for ideas such as peer production and the Maker movement in general – and indeed, we als found them to relate to self-expression in ICT4D-settings: Curiosity about the activities of others in the group as well as sharing of ideas and even whole 3D models happened frequently and proved to be quite motivational. Cases such as the remixing of a model across camp boundaries serve well to illustrate the power of distributed digital fabrication in changing bits to atoms and vice versa (Gershenfeld, 2005) – a child can build on the work of others virtually and subsequently, both can make physical items from their virtual collaboration. This effect of collaborative work that breaks the digital-physical boundaries in non- or semi-professional settings also scales to much bigger projects such as the DIY prosthesis we introduced in the related work (Krassenstein, 2014).

For our cases, the collaboration aspect of working in the same world in itself quickly proved to have potential with children learning and copying from each other, confirming previous work with similar tools such as Minecraft (e.g. Duncan, 2011). Furthermore, this obviously also relates to the question how to introduce and facilitate appropriation which is hardly surprising since Pipek (2005) explicitly talks about how appropriation processes happen collaboratively. However, it was notable that, for the most part, there was a significant element of face to face interaction in the collaboration we could observe. This might have been due to the convenience and social conventions when participants were in the same rooms, but we suspect that the limitations of the available tools and interfaces to support the work are also relevant factors (more on this below). If we look at Maker collaborations in the world in a more general sense, we see similar effects – of course, there are virtual collaborations which are vital for the successes of the movement (Tanenbaum et al., 2013) but there is also a significant emphasis on actual face-to-face collaboration: The Maker culture places great emphasis on real-world events such as Maker Faires, the *FAB* series of conferences and the social meeting and collaboration aspects of Makerspaces and Fab Labs, indicating the importance of a balance between physical and virtual collaborative work but also shortcomings in the currently available ICT for collaboration (Ludwig et al., 2014a).

On this note, I will now turn towards some of those tools and discuss the ones we worked with in more depth since they are one of the pillars supporting the work which can be done by Makers and emerged as a central aspect related to ICT4D and self-expression in our analysis:

8.2 THE BAD (AND WHAT WE CAN DO ABOUT IT)

In a general sense, it is quite possible to achieve notable, quick learning and understanding successes with currently available, playful and collaborative tools such as Minecraft or CubeTeam as previous researchers have found out in different settings – for Minecraft see e.g. Short and Short (2012). However, there are hindrances and significant gaps in the learning and appropriation processes given the limitation of those tools as well as the current 3D printer ecosystems, confirming previous work calling for novel tools and interfaces such as Willis and Gross (2011). This part of my discussion will focus on possible *implications for design* for future systems I was able to derive from our analysis – or, to put it another way, all the following themes especially relate to my second research question which aimed at how to design ICT for Making in ICT4D:

Orientation and camera control related to many problems relating to orientation in 3D space and executing tasks in conjunction with appropriate camera position. This is, however, crucial for successful 3D modeling which is why we would argue for the inclusion and exploration of alternative ways of navigation: e.g. utilizing 3D mouses, which map directly to three axes, or even game controllers to support familiar appropriation patterns. We saw indications that game-inspired camera and/or movement control might be beneficial – as we reported on, some of our children were quite adept at using the "WASD" movement control mode in CubeTeam. Furthermore, the exploration of virtual reality with higher degrees of immersion in the 3D-space (e.g. utilizing virtual reality glasses such as the Oculus Rift) might be sensible. Switches between navigational modes as employed by CubeTeam either should be avoided or introduced especially carefully and with appropriation support in mind.

Regarding a (lack of) *coordination and collaboration features*, even if such processes mainly happened face-to-face in Palestine, in the more long-term project in Germany (as well as thinking about future, more distributed collaborative projects), we see the need for more advanced coordination mechanisms than currently available in most playful tools for digital fabrication. Automated ownership signifiers (such as color or signs) would be worth exploring. If we turn to the success of voice chat in online multiplayer gaming (e.g. Teamspeak), this line of thought might also be worth exploring. An interesting option might be to constrain (voice) chat channels geographically, meaning a conversation could only be heard or read if in close proximity to the relating structure.

Usability and UX issues are an issue frequently covered in CSCW and HCI, especially when talking about how to support novices in their work with complex technologies. It is not surprising that we found many such issues relating to things like modal navigation, less-than-optimal icons and similar issues in the tools we utilized. Future tools should support a centrally configurable interface in which e.g. leaving a project could be remotely disabled – at the very least, there should be a very simple "bring me to my group"-control. The actual modeling UI should be as minimalistic as possible and also configurable, offering only basic operations (e.g. placing and deleting a building block) and subsequently getting more complex (undo, copying blocks, etc.).

The construction and limits of current 3D printers can result in problems when trying to print something that works in the virtual but not the physical world. Future tools should be aware of those device-specific limitations. They should not only attempt to correct them automatically or simply do not allow certain operations but rather provide a more gentle appropriation supporting mode in that they should make the user aware of why something like a significant overhang probably will not print well, e.g. by the use of color codes. Automated notifications and animations (such as a printing process simulation) might also be a way to supplement this. Similar results and ideas have been proposed in Ludwig et al. (2014a). With other, less restricted, 3D printing technologies such as laser sintering getting more affordable, this problem might solve itself in the medium-term.

Furthermore, there is a gap between the ease with which children are able to pick up basic 3D modeling and the fact that the 3D printing itself necessitates a lot of previous technical knowledge. This leads to a certain "black box" perception of the 3D printer, as phrased by Ludwig et al. (2014a). Hence, future educational tools should offer more integrational features (speaking overly simplified: Offering a *print now* button), integrating the printer, modeling tools, control software and print material to a denser ecosystem. Actual printers for education should be designed safer, more encapsulated and offer basic *it just works*-settings, based on which exploration can be initiated – unlike the current state of affairs where a significant amount of configuration and knowledge has to be done / acquired *before* the first print. A printing simulation could serve as an intermediate step in such a process.

With this, I would like to close my discussion about the core empirical results. Before I start to turn towards future work, I will now briefly reflect on our Methodology.

8.3 ON OUR METHODOLOGY

Actively going in the field, doing interventions and trying to do systematic research in such settings might be considered critically by some – and maybe rightfully so. To approach this in a top-down fashion: Some people might even question the basics of our approach, namely qualitative, situated approaches which become more and more prevalent in HCI. Instead of framing an answer myself, I would like to quote more established researchers who responded to this better than I could:

> *"There are many complex, socially based phenomena in HCI that cannot be easily quantified or experimentally manipulated or, for that matter, ethically researched with experiments [...] In addition, technology is rapidly changing – just think of developments in mobile devices, tangible interfaces and so on – making it harder to abstract technology from the context of use if we are to study it effectively. Developments such as mediated so-*

> *cial networking and the dispersal of technologies in ubiquitous computing also loosen the connection between technologies and work tasks that were the traditional cornerstone of HCI. Instead, complex interactions between technologies and ways of life are coming to the fore. Consequently, we frequently find that we do not know what the real HCI issues are before we start our research. This makes it hard, if not actually impossible, to define the variables necessary to do quantitative research."* (Adams et al., 2008)

I feel, I cannot add much to this but to state that especially in complex ICT4D settings, the social context may become even more important than in "regular" areas. Furthermore, the areas of Making and digital fabrication are a prime example for rapidly evolving and changing and the notion of HCI-motivated research in those domains is even more recent, making qualitative approaches sensible. Of course, that entails the issue of generalizability I already touched on – for now, for the state and body of work available, abstractions should be handled very carefully but I believe our results are thick enough to allow for tentative predictions and further study / test iterations, especially when cross-analyzed with our related work in other settings. This is further supported by the past successes of our research group in come_IN as well as in other projects by utilizing similar methodological frames of reference, see Aal et al. (2014); Schubert et al. (2011) focused on the computer clubs as well as Wulf et al. (2013a,b) for research approaches *on the ground* in conflict settings (namely regarding political activists). For more detail on issues regarding generalizability, I would also again like to reference back to (Wulf et al., 2011; Brödner et al.).

Additionally, I would like to reiterate my considerations from 5: A Participatory Action Research motivated approach is, to me, one of the most honest methodological framings when working in conditions such as refugee camps where trust, lots of communication and participation are important and the role of a detached and neutral-observatory researcher almost certainly would not work well, maybe even make the local community suspicious and / or unwilling to participate. After spending time in the field, I can confirm this point of view personally, but more importantly, it has also already been made and elaborated on in Rohde (2013, 2004).

In essence, I believe our methods to be valid and reasoned, however I also think that every scientific approach should be analyzed and discussed in depth which is why Alexander Boden and myself put our methodological approach, its reasoning and its grounding in HCI tradition up for discussion in Stickel and Boden (2015). This contribution is not published yet but accepted and will be available soon.

We are looking forward to discussing the methodology in depth and with researchers from different disciplines, especially those not from HCI, in 2015 on an ethnology conference centered around DIY[1].

1 The conference is called "Do it! Yourself? Fragen zu (Forschungs-)Praktiken des Selbermachens" and will take place March 2015 in Vienna, Austria.

9 OUTLOOK

I will continue to do research in the intersection of HCI and Making with a focus on digital fabrication as a doctoral student immediately after turning in this thesis. This is why the following outlook will be a bit longer than might be usual for a Masters thesis: It will center on Fab Lab Siegen as the research infrastructure I will base a lot of my future work in and upon. As a project example from Fab Lab Siegen, I will also introduce the Resha laser before finally closing with some personal words.

9.1 FAB LAB SIEGEN

Fab Lab Siegen is a student-run project initiated by myself. Its aim is to found, establish and run a Fab Lab at our university. Siegen. Apart from being very close to my heart and interests, has found its way into my thesis since it serves well to illustrate some of the intersections of HCI and Making I am interested in and which I believe our research group might be well positioned to cover based on research tradition, a focus on socio-technical systems and emphasis on practice as well as users.

First of all, it has to be noted that Siegen seems to have a remarkably broad and strong bottom-up DIY culture. The city is not very big (just under 100 000 inhabitants at the time of writing) and often associated with a rather conservative mentality. However, if one goes a little deeper, one can find a very active Hackspace, an Urban Garden, foodsharing initiatives and many other projects which go in a certain bottom-up direction. I have written about this phenomenon in more detail in Stickel et al. (2014a). Suffice to say at this point that there seems to be fertile soil for a Fab Lab in Siegen which is one of the main reasons I had been toying with the idea of establishing a Fab Lab or a Makerspace for some time. In 2014, I managed to substantiate those ideas, acquired funding of about 70 000 EUR for infrastructure, (after much politics) managed to get approval for space on campus and, bit by bit, a tentative community of interested people started to form. Fab Lab Siegen will hopefully open its doors in spring 2015, but even without an actual physical space in 2014, we did our best to attend Maker Faires, organize 3D printing workshops, hold talks[1] and help out some startup founders. Fab Lab Siegen is intended to be an open space for all interested parties but also as a

1 See www.oliverstickel.de/publications

research infrastructure for my future work which is why, in the following sections, I will try to explain in broad strokes what we might do during the next few years:

9.1.1 *Approaches to education*

Current Fab Labs (at least in Germany) often are relatively autonomous which has many benefits but there might also be a lot of missed opportunities: Currently the path through the educational system is, of course, scaffolded by institutions such as schools or universities. This is why I am planning to investigate into the integration of a Fab Lab into institutional education by way of experimental and interdisciplinary courses and seminars. Outreach and exchange programs with local schools (among others via the come_IN project) as well as the local economy are planned to supplement this. Especially our experiences with school children will also flow back to come_IN at Palestine (and vice versa). but also All educational activities in the Fab Lab will be grounded in constructionist, situated approaches to learning and (non-traditional) examinations – over time, we will hopefully also be able to iterate on the paedagogic concepts as well as the ICT we will use by constant participatory research and reflection.

9.1.2 *Supporting and investigating very different projects and work*

In this thesis, I elaborated on how we essentially helped to give come_IN a new spin towards digital fabrication. I believe that there are many such opportunities at a university. For example, "RemoNET", a research project about E-Mobility focusing on E-Bikes has already expressed interest to build a self-repair corner for their participants in the Fab Lab. The more projects from different disciplines access and participate in the Fab Lab, the more interesting results about appropriation processes relating to digital fabrication technologies we should be able to gather. What we learn and build based on those experiences (e.g. novel or better interfaces for playful digital fabrication or new DIY machines) will also influence further Making efforts in come_IN. Furthermore, if we understand a Fab Lab as a place to tinker, explore and invent collaboratively, there might very well be a need for appropriate ICT to share knowledge and to document and remix projects on a local and maybe even global level – HCI and CSCW are predestined to develop such systems.

9.1.3 *Community aspects*

Fab Labs are inherently socio-technical. They are places where innovative machines for production are available to *human Makers*. Hence, the formation and support of a situated, local Maker community is crucial for every Fab Lab. Processes of community formation and support are, of course, concerns for CSCW and HCI, especially if we are talking about communities which form around and with the help of ICT, e.g. by understanding the technical systems as boundary (negotiating) artifacts – Fab Lab Siegen will be a highly interesting infrastructure for investigations in this direction. Of course, there is also a dimension of a global community in that Fab Labs often collaborate and try to share knowledge. We will try to participate in such projects, Maker Faires and the FAB-conferences and try to investigate deeper into the relation between localized, face-to-face collaboration and distributed collaboration mediated by ICT (as well as try to make this ICT better, if the need arises).

9.1.4 *Economical aspects*

Siegen has a strong tradition of heavy industry as well as the SME-sector. There are a few more design-oriented companies and in recent time, the university as well as the city also tries to push human-centered, creative concepts and start-ups. A mesh of financial, educational as well as networking support structures is evolving, which is also supported by local foundations. All those aspects seem to indicate an at least tentative willingness to try out and work with alternative and/or innovative approaches to product development and production. We will try to work with those initiatives by offering the Fab Lab as a venue for startups or SME to develop products, find inspiration and/or knowledge. Initial contact and the promise of collaboration have already been made. However, we will also strongly emphasize the fact that this is no one-way street and expertise as well as (as far as possible) artifacts, designs and/or products will have to flow back to the Fab Lab community, advancing a product or a company as well as the Fab Lab in turn. This is an interesting and very relevant discourse and I believe there is quite a bit to learn and transfer here from the discourse in Participatory Design (Ehn, 2008) which also continues to act in a field of tension between market demands and empowerment ideals.

9.2 PROJECT EXAMPLE: THE RESHA LASER

In the following sections, I will report on the ongoing work with the “Resha” DIY laser cutter as the first big Fab Lab Siegen project. It serves well to illustrate some of the potential I see in our Fab Lab: Laser cutting is not as far along on the way to consumer availability and affordability as 3D printing, but there are quite a few factors which make it interesting for my work, such as the fact that it is less complex than 3D printing (only 2 axes) which could be relevant for the introduction of beginners (such as children in the come_IN clubs)

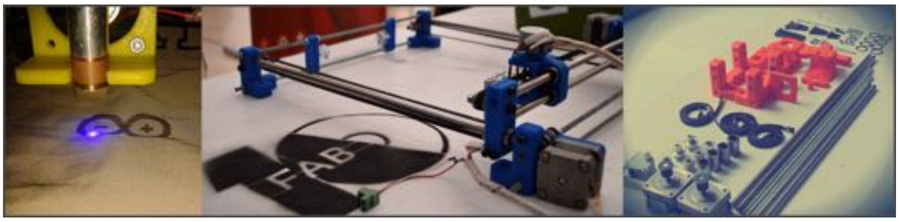

Figure 11: The Resha Laser (photos from reshalaser.com)

to digital fabrication. At re:publica 2014 conference, I got to know the team behind the project Resha Laser[2] (see fig. 11), an open source, affordable DIY laser cutter / engraver based on off-the-shelf as well as 3d-printed parts, an Arduino and a custom DIY but open sourced control shield for the Arduino. It is accompanied by a basic control application (in beta at the time of writing) in which users can draw designs they wish to cut / engrave directly or load them as images, offering up a wide range of input options. A mobile app with similar functionality is planned. The Resha is explicitly intended to be well suited for beginners as well as possible applications in ICT4D-settings. The machine is relatively low-powered – it can cut things such as felt or cardboard and engrave materials such as wood.

Moushira, the project leader has spent quite some time in the Sinai, working ICT4D projects.

My expertise with laser cutting is quite limited and the technology itself can be dangerous (especially in a DIY beta product) which is why I decided to discuss and evaluate a Resha at the *Teaching to Tinker* workshop[3] at the NordiCHI 2014 with Makers and educational experts from all around the globe. In Stickel et al. (2014b), we described our goals for the workshop which included collaborative assembly of a Resha, hands-on testing, brainstorming for projects as well as problems with the machine.

9.2.1 *Making a Resha*

Before the workshop, we had to build and test (see fig. 12) a Resha in order to bring it to NordiCHI. After sourcing or 3D printing (in a lab at our university) all the necessary parts, we then partnered up with hackers from the local Hackspace[4] in order to collaboratively figure out how to build the machine – the documentations available on the Resha homepage were quite sketchy at the time and especially the software was in beta stage. Another local enthusiast, Ulrich Radig, also chimed in and helped to re-design as well as to etch the custom PCB for the project. This illustrates once again the beauty of making and open source – people with different skills come together and

2 See `www.reshalaser.org` for more information as well as `https://github.com/RishaLaser` for all the technical specifications, source code and 3D printing files.
3 `www.teachingtotinker.com`
4 Hackspace Siegen or HaSi – `www.hasi.it`

build something transcending the individual skills. Of course, we documented our experiences and send them back to the Resha team to help them in turn.

The build itself took some 60-70 person-hours until the Resha more or less worked as it should. The process involved lots of improvisation such as modifying the PCB design, hacking an old ATX power supply or using a drill press to vary and test the focal distance of our laser (this is shown in fig. 12). We learned many things about electronics, 3D printing and other situational aspects during the process. I also took field notes during the building process and tried to observe the participants during. There were a few notable issues with communication, coordination and especially documentation such as a fragmentation between google docs, GitHub, a homepage and a Wiki, which lead to version conflicts and confusion. There is not enough material for a full-fledged analysis yet but again, everything points at a great need for HCI and especially CSCW support in such globally and locally distributed collaborative maker projects, relating back to the implications for future work I talked about earlier.

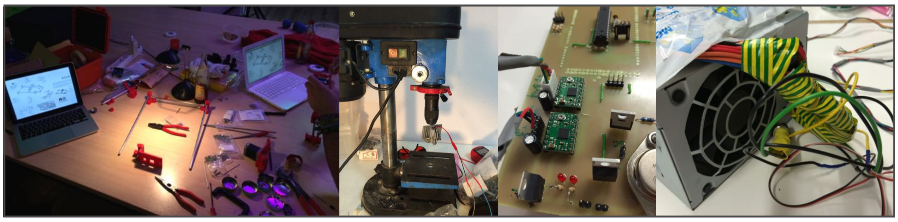

Figure 12: Building a Resha at Hackspace Siegen.

9.2.2 *Workshop at NordiCHI 2014*

At the workshop (see fig. 13), the participants which came from all around the world and included Makers and scientists ranging from PhD-students up to professors, all working with Making in educational settings, were invited to try and assemble the machine in a hands-on fashion after I gave a brief introductory talk[5]. Furthermore, I asked them to talk about what they were doing, ask questions and share their experience in a fashion somewhere between a thinking aloud user test and a heuristic expert evaluation. After the completion of the machine, I demonstrated its capabilities in a participatory fashion, welcoming input and also hands-on interaction by the participants. The reason I took the lead in the actual demonstrations were a) the potential dangers of a laser and b) the simple fact that the control software is still in beta and tends to crash for many obscure reasons

5 Slides can be found on my homepage: `http://www.oliverstickel.de/publications/`.

and sometimes, a CLI interaction with the Resha is necessary. Given the limited amount of time (about 1.5hrs), this was not something I wanted to burden the participants with. Subsequently, we had an open and reflective discussion. I took field notes during the whole process and after the workshop, I analyzed them (again, using TA) together with the notes from the building process in Hackspace Siegen. Notable themes were:

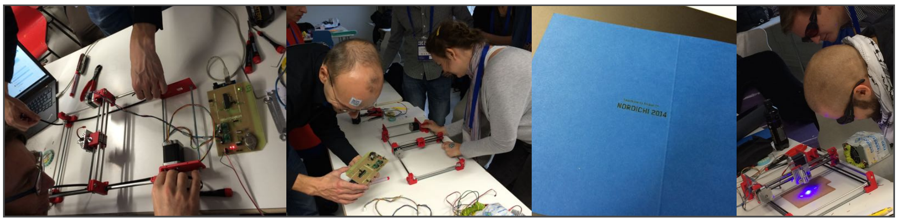

Figure 13: Resha at NordiCHI

2-AXIS CNC: A laser cutter (or, if the laser would be replaced by a pen, a pen plotter) was viewed as a very interesting educational entry point to CNC: Such a machine is far less complex and cheaper than a milling machine or a 3D printer in that it has fewer axes and less complex toolheads – on/off and power regulation vs. a myriad of toolheads, feedrates and speeds for a milling machine and temperature gradients, retraction rates and other aspects in 3D printing, just to name a few. The introduction of a relatively approachable and cheap machine such as the Resha was welcomed. As such, it might be beneficial to think about introducing laser cutting first, then switching over to 3D printing in order to scaffold the appropriation of digital fabrication in ICT4D and maybe other settings as well.

MAKING THROUGH TECHNOLOGY / MAKING TECHNOLOGY: An open hardware project such as the Resha has the potential not just to empower learners to make things *through* advanced digital fabrication technology but also to understand and make the actual machines, which was viewed as a quite powerful proposition. This also relates to the fact that due to the DIY nature, problems will inevitably arise during the building process which invokes situated problem solving, an important skill in ICT4D. However, there were concerns that it would be hard to hit the sweet spot, i.e. not to pose insurmountable problems. Good documentation and kits for specific, difficult parts were suggested as solutions.

BRIDGING COMMUNITIES / DEMOGRAPHIES: The Resha was assessed as an interesting opportunity to bring together experts from different domains and age groups with learners, even children during the building process of the machine but also during making things with it. Implicitly, the experts at the workshop touched on something we also found in the Making@Palestine-study: Digital fabrication technologies can serve as sort of boundary (negotiating) artifacts.

SCROUNGING: Many parts for a Resha can be scrounged from old electronics such as scanners an/or DIY fabricated. This was also viewed as promising regarding education about sustainability – and for empowerment in ICT4D settings.

DANGERS: The dangers of a laser were emphasized. The experts stated that the Resha should not be open but rather have a filtering shield tuned to the wavelength of the utilized laser which in turn also would prevent curious fingers from burning themselves with the laser beam. This aspect is similar to what we found in Making@Palestine where we had to be very careful to prevent children from touching the hot printer. However, a laser can be shut off in a microsecond (sensor-controlled, if necessary) while a 3D printer is still hot for minutes after it has been turned off. This might be beneficial when working with children.

Based on the results of the workshop, we are currently in the process of advancing the development of the Resha in order to be able to deploy and research it in a variety of settings in the future.

9.3 SUMMARY

I believe that there is a good chance that Fab Lab Siegen will evolve into a base for in-depth work regarding HCI and Making in theory and practice. As far as I can see now, we are immediately in a good position for deeper ventures into educational aspects through practice-based meta research on the interfacultative academic courses we will hold in the Fab Lab, but also through workshops and lectures for and with the local population (there already are offers for workshops centered around Arduino, drones and sewing, for example).

We also already have strong ties to Hackspace Siegen as an established local hacker community and it will be very interesting to see how Fab Lab and Hackspace will interact, benefit each other and maybe even merge in parts in the future, evolving into a new, bigger community of practice. This aspect (not necessarily limited to the Hackspace) also can be viewed as a puzzle piece towards the work of my colleagues who look at the importance of regional collaboration and joint learning efforts Rohde and Wulf (2013); Reichling et al. (2010), albeit from a more alternative angle.

In a sort of intersection between CSCL and ICT4D, we will continue to work with come_IN in Germany as well as the West Bank. Carrying out another 3D printing study in our German clubs is already in the works and the deployment of the Resha laser is, as already mentioned, prepared and planned. We will continue to remotely follow the appropriation process and the emerging 3D printing projects in the Palestinian come_IN clubs. We also will expand on the aspect of collaborative, expressive storytelling in an international fashion by fostering collaboration on 3D printing projects between our German and Palestinian clubs. This could be especially powerful because meaningful artifacts created by children thousands of kilometers away can be printed *right here* and convey a physicality and directness different from purely digital collaboration. Relating to the results of our study: After handing in this thesis, I will make the core empirical results available to CubeTeam and its development team. I have already had some contact with them and they were very interested in our work. I hope to see some of our implications for design reflected in CubeTeam (and maybe other tools as well). Should that happen, we will of course test it again in the field.

10 CLOSING WORDS

To kick off this section with some personal words, impressions and a look back: I started my HCI masters course as a semi-motivated student annoyed by bulimia-learning and with a background in quite quantitative, psychology-focused cognitive and media sciences. Subsequently, I got thrown into the world of situatedness, qualitative studies, in-situ fieldwork, context-focus and ethnography – and more autonomy. After a while, the world of *Making* also came into play and I started on a rapidly evolving journey which ended up with myself working in refugee camps in a conflict-torn area, trying to help empower children, with me giving talks and participating in workshops on the topic allover the world and somehow even starting a Fab Lab and acquiring more money and infrastructure to build it than I have ever had to manage before.

"Bulimia learning" is a phrase used by many students nowadays – it means having to learn huge amounts of subject matter by heart and puking everything out in written exams as fast and as literal as humanly possible.

This is not bragging – far from it, it is an admission: All this happened quite fast and in a lot of respects it is daunting, even a bit scary. The work on this thesis has helped me to coalesce everything into a narrative, showing contexts and relations – this might also help explain the rather broad range of topics and issues I covered. However, to me, they form a intricately connected, yet still emerging entity of Making, digital fabrication and a HCI perspective on their interplay. I will probably never be able to understand this entity as a whole but I hope, I managed to convey some of the sense of its intricacy, interconnection and maybe a bit of belief in in the revolutionary potential of Making onto my readers.

10.1 ACKNOWLEDGEMENTS

With this, I would like to close my thesis by way of some words of thanks: Despite quite a bit of chaos and maybe too much anarchy, the amount of freedom I have experienced as a HCI student in Siegen was amazing and very empowering. The fact that there is only very limited hierarchy and facts beat rank (almost) everytime is amazing to me and has enabled me to do a lot of really interesting things over the last few years. Hence, my heartfelt thanks to the masterminds – Volker Wulf, Volkmar Pipek, Gunnar Stevens and Markus Rohde should be named here.

Further thanks go to Dominik Hornung, my main "partner in crime" in Palestine as well as the Fab Lab project for his very unagitated counters to my sometimes impulsive behaviour and ideas. Hackspace Siegen[1] also deserves a big thanks for all the help with Resha, as does Ulrich Radig for his work on the PCB. Of course, I would also like to thank Thomas von Rekowski, Konstantin Aal and Markus Rohde for their invaluable feedback on this thesis. Last but far from least, my biggest *thank you* goes to all the amazing volunteers and participants and other people in Palestine, especially George Yerousis who pours endless amounts of free time – and a significant part of his soul – into the project.

1 No names mentioned, hacker ethics and all that.

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