3D Printing with Marginalized Children – An Exploration in a Palestinian Refugee Camp

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Abstract. We work with a multi-national network of computer clubs for families and children called *come_IN*. In two such clubs (located in Palestinian refugee camps in the West Bank), we worked with children on playful approaches concerning 3D modeling and 3D printing within a five-week, qualitative field study. Based on this study, we report on the achievements as well as on the difficulties of digital fabrication and of "Making" in developmental and educational contexts. The benefits are related to an overarching theme of *self-expression* where the main focus was on dimensions as *playfulness, approachable complexity, individualization, immediacy and physicality* and *collaboration* as well as *motivation*. The problematic aspects were mostly related to socio-technical limitations concerning the themes of *orientation and camera control*, the *lack of coordination and collaboration features*, *usability and UX issues* as well as *the construction and limitations of current 3D printers*. Based on those findings, we have derived implications for the design and the appropriation of future systems for digital fabrication with children, especially in developmental / educational settings, such as improvements of their collaboration support or better feedback mechanisms regarding the system status towards the end user.

Introduction

The 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. Bottom-up communities and associated Makerspaces or Fabrication Laboratories (Fab Labs) are flourishing world-wide. These 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, and make them to a fascinating field of research. Digital fabrication and the socio-technical movements like the Maker culture increasingly blur the lines between professional and voluntary work. CSCW is called to investigate those trends and help to shape future developments – which already start to happen all over the world. An area where Making might show distinct potential is in ICT4D-related settings. Less privileged and education-focused settings might benefit from its potentials regarding empowerment and socio-economical change. This is why we decided to empirically investigate into such case: We focus on marginalized Palestinian refugees in the West Bank within the framework of our global network of constructionist computer clubs for children called come_IN (Aal et al., 2014). Come_IN is a long-term venture encompassing many projects ranging from playful programming up to film projects – a sensible setting for a deeper investigation into Making. Two of our researchers spent five weeks in two come_IN clubs in the West Bank, brought a 3D printer and worked with several groups of children regarding playful and also collaborative approaches to 3D modeling and 3D printing. The study was exploratory, qualitative and led by the field. This approach is grounded in the belief that the socio-technical CSCW and ICT4D issues we are interested in are highly complex and inextricably embedded in a local context and interrelated to complex communal, societal and other structures, values and practices. This position necessitates a deeper, situated and qualitative approach (cf. Adams et al., 2008).

As a central focus of our study, we found that 3D printing seems to harbor quite a lot of potential for developmental, educational contexts (especially regarding to individual self-expression), yet still faces many socio-technical problems that CSCW and HCI are called to solve. Thus, we will first introduce the related work before elaborating on the research setting. Subsequently, we will report on our results, structured along the overarching themes of benefits and problems. Finally, we will discuss our results with a focus on implications for design.

Related work

Making, Do-It-Yourself (DIY) and hacking, backed by digital fabrication technologies have seen a significant upwind 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 digital fabrication machinery[1]. These developments were also responsible for the formation of an increasing number of related communities, which build physical spaces to pursue Making. The number of Fabrication Laboratories (Fab Labs), Hacker- or Makerspaces (Gershenfeld, 2005) is steadily growing[2]. 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). There have been investigations into bringing together DIY electronics with other crafts (e.g. Buechley and Perner-Wilson, 2012; Weibert et al., 2014) or even into DIY biology (Kuznetsov et al., 2012). It has been noted that 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). Understanding and treating Fab Labs and Makerspaces as boundary (negotiating) objects (Star and Griesemer, 1989; Lee, 2007) has been indicated as potentially helpful for such issues (Ludwig et al., 2014b). In a more macro sense, Kuznetsov and Paulos (2010) 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 -sites for innovation and pose that HCI has a key position in Making. Furthermore, the Maker movement often has aspects of a counterculture to mass-production and consumption (Tanenbaum et al., 2013; Moilanen and Vadén, 2013) in that it utilizes and develops technologies but also places great value in doing so in open, democratic community spaces. Values such as sharing, learning and teaching, playful and collaborative exploration, mutual support and socio-economic change are emphasized (Hatch, 2013). Digital fabrication is even hailed as the next stage in the digital revolution (Gershenfeld, 2012), opening up production of physical goods in a similar fashion as the PC did for the digital domain, potentially disrupting existing socio-economic patterns (Troxler, 2013).

The central learning theory the come_IN clubs (which frame our research) are based on is *Constructionism* (Harel and Papert, 1991). It focuses on experiential learning and holds that learning does not happen through instructions but rather through active learning facilitated via the construction of individually meaningful artifacts through ICT. There are long-running and successful related projects such as Scratch (Resnick et al., 2009) centering on constructionist approaches to programming. This obviously fits very well with digital fabrication and Making (cf. Gershenfeld, 2005) with many successful educational Maker projects based on constructionist approaches, cf. Blikstein (2013) for an extended overview.

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[1] The Printrbot Simple, a compact 3D printer we used for this study costs 349 USD as a kit, just to give an example. The printer works with Fused Filament Modeling – basically similar to the working principle of a hot glue gun, however, computer controlled and extruding harder plastic.

[2] See http://fablabs.io for a global overview

The concept of appropriation (Pipek, 2005) is also relevant for our project and related to learning: 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 of Dourish (2003) which is about how users fit ICT in their practices by adoption and adaption. Appropriation entails end user customization of ICT but is more encompassing. It can also relate to changes in practice and possibilities of changing the system in ways not anticipated or intended by its designer. Again, community aspects are relevant since appropriation is often associated with social networks of users, sharing and exchange (cf. Pipek and Kahler, 2006; Wulf et al., 2015). The relevance of scaffolding appropriation for 3D printing has been emphasized in Ludwig et al. (2014a).

As already indicated, Making might offer significant potential for developmental aid, empowerment and help in marginalized settings (Mikhak et al., 2002). Projects such as DIY prosthesis, which are very cheap and which can be manufactured by amateurs in the field (Krassenstein, 2014) or 3D printable tools to support personal hygiene in disease-ridden areas (Gardner, 2014) are already being deployed. 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). Furthermore, ICT4D aspects are connected to teaching and learning in that bottom-up constructionist education. Empowerment via Making and digital fabrication can help to bridge the digital divide that is prevalent in developing countries (Kafai et al., 2009; Aal et al., 2014).

Research gap: As the related literature shows, Making and digital fabrication seem to have relevance for a broad variety of areas. However, those areas are essentially linked through a form of work – the *Making* itself – as well as new forms of collaboration, sharing and learning which potentially result in socio-economic change on a grassroots level. One of the prevalent areas where Making already seems to show such impact is ICT4D – however, there is a lack of empiric, situated fieldwork around the potentials of Making in such settings, especially when looking at changes emerging from a *bottom-up* fashion. At the same time, there are indications that current ICT for Making is often less than optimal from an usability perspective. Understanding the two come_IN clubs in Palestine as an educational, bottom-up initiative in a developmental setting, we have access to an apt research field to help fill this research gap.

1 Research setting

During the 1948 Arab-Israeli war and the 1967 war, many Palestinians were expelled or fled from their homes in what is now a part of Israel. This led to the establishment of refugee camps on the Palestinian territories and surrounding countries.

Originally intended to be short-term, those camps still exist today and face unsustainably growing population, makeshift infrastructure and insecure socio-economic structures. Some camps have 40% unemployment rates and a population of up to 60% under the age of 17, packing more than 10000 people into an area of less than one square kilometer[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. So, their existence is a political reminder of the populations' lost homes and a complete social integration within the mainstream population is politically problematic. Yet, at the same time, camp inhabitants are often treated as second class citizens and there is a notable gap in social standing between mainstream Palestinians and inhabitants of the camps (cf. Aal et al., 2014; Wulf et al., 2013). Education in the camps is basic and provided by the UN relief organization (UNRWA) in gender-separated camp schools.

Over the last decade, our research group has built a network of "come_IN" 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 projects based on ICT. Today, the come_IN network consists of multiple clubs in Germany, one in the US as well as two in Palestine, both located in refugee camps. come_IN is based on the computer clubhouse project in the United States (Kafai et al., 2009) but expands its focus on ICT4D through aiming at social integration (cf. Stevens et al., 2005; Schubert et al., 2011). Our clubs mainly target areas with a significant migrant population where integration is a problem. For example, in Germany, the clubs try to engage the German-Turkish community, while in the Palestinian clubs, issues are even more manifold, ranging from the regional conflicts and instabilities over gender inequalities up to the marginalized state of the refugees in their own society. Furthermore, come_IN is grassroots-oriented: Each club is established in a bottom-up fashion together with local actors. Over the years, a successful model has emerged, consisting of coupling the clubs with institutions like elementary schools in Germany or youth centers in Palestine that help to provide continuity, space and situatedness. Collaboration with a local Palestinian university has also proved to be very valuable and can provide (student) volunteers as acting tutors, bring in innovation in the form of new ICT or project ideas and facilitate meaningful collaboration between children, adults, parents and students/researchers (Aal et al., 2014).

We describe the come_IN structure as well as the complexity of the Palestinian clubs in Yerousis et al. (2015). However, it has to be said that the Israeli-Palestinian conflict is a matter of daily life in the camps. An example are the frequent raids of the Israeli Defense Forces which often involve violence and in some cases death. Getting access to ICT and the Internet at home is problematic and further hampered by the fact that many refugees do not have the skills to use such technologies. At this point, the come_IN approach offers opportunities to bridge this digital divide,

[3] The numbers relate to the camp of Jalazone as estimated by the camp administration.

Figure 1. Come_IN sessions in Palestine.

especially regarding the gap between the in-camp and the out-camp society. The two come_IN clubs in the West Bank are located in the refugee camps Al-Am'ari and Jalazone which are both located in/near the city of Ramallah. In both camps, the clubs are housed in central community 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 Birzeit University in cooperation with the camp administration (Aal et al., 2014). Participants gather at the come_IN clubs voluntarily once a week for joint sessions and individual projects which are usually related in a meaningful way to their situation, values or experiences (see fig. 1). Up until mid-2014, the ICT used in the come_IN clubhouses focused mainly on entirely digital representations such as programming, for instance with Scratch (cf. Weibert and Schubert, 2010). However, we are aiming to expand all our clubs towards the digital-physical intersection. Therefore, we started to explore the video game Minecraft tentatively as a playful, collaborative 3D modeling tool in one of our German come_IN clubs. 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 in ICT4D.

Research Methods

Given the nature of Making which, as already implied, is evolving and developing quite rapidly and our goal of exploring the potential of digital fabrication within the constructionist come_IN setting, we favored a Participatory Action Research (PAR) motivated approach (cf. McTaggart, 1991) where we went into the field, implementing a change by means of introducing the 3D printer. Generally speaking, PAR is about researching community structures and effects utilizing the instruments of change and action. The researcher actively takes part in the studied community and the community itself also actively takes part in the research. We knew that we necessarily would implement change and action by introducing 3D printing. Given the importance of trust and personal contact in sensitive, marginalized refugee settings, it was also clear that we had to actively take part in the sessions as tutors, support staff, or whatever would become necessary. We also knew that our participants should have the power to decide about what to make, to work in groups or individually and other similar decisions that might be pre-determined by researchers in other settings. Given such a constellation, PAR offers an honest and practical framework.

In 2014, two researchers from our research group in Germany (the founding institution for the come_IN network) visited the two Palestinian clubs. Members of our research group visit the Palestinian clubs quite regularly when doing field studies. We had already done exploratory work with children and 3D printing in Germany. This led us to the idea that our Palestinian colleagues might be interested in this relatively new technology and its digital-physical alignment. They subsequently confirmed their interest, so we decided not just to send a 3D printer but also ourselves to support and study the appropriation of the new technology within the very special settings of the refugee camps. While we were in the field, we moderated the club sessions: First, we introduced 3D-modeling and printing live by printing a demo-object and demonstrating basic modeling interactions such as moving the viewport. As a 3D modeling tool, we used CubeTeam[4] (see fig. 2, left). It is similar to the video game Minecraft: 3D models are assembled from small cubes in a "Lego"-like fashion. CubeTeam is also collaborative as multiple actors can work in the same world. 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"-keyboard movement (which, however, can be enabled, too). The children were free to create their own projects in CubeTeam with us and the volunteers always available to help. Finished projects were then 3D printed by us in situ. We used a Printrbot Simple 3D printer which is compact, has a build volume of $15cm^3$, prints with PLA (a cheap and easy to handle plastic) and is easy to fix due to its simple design and many off-the-shelf parts.

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, a lack of a culture of attendance and punctuality in the camps which also affects other institutions, such as the schools (cf. Yerousis et al., 2015; Aal et al., 2014). We observed the sessions, took extensive field notes (about 60 pages) as well as photos and talked to the children and the volunteers throughout the process. Our activities had to deal with the language barrier and we were mainly depending on volunteers for translation. These conversations were ad-hoc and a bit chaotic most times as the course of the club sessions were often unstructured, the environment in the camp chaotic, the language barrier problematic and the fact that we had to fulfill many roles at the same time (researcher, tutor, operator of the 3D printer, IT-troubleshooter, ...) very difficult. Hence, our analysis mainly relates to our observations and field notes. All names were anonymized due to privacy and security concerns. Analysis was done using Thematic Analysis or TA (Braun and Clarke, 2006). This was deliberately started quickly in the field to bring up questions and sharpen the research lens through daily exchange and discussion of the

[4] www.cubteteam.io

notes and memos between the field researchers, interspersed by occasional Skype calls with senior researchers at home to ensure inter-coder reliability. The analysis was then finalized at home together with researchers not involved in the field work. Furthermore, the 3D printing infrastructure was left in Palestine to remotely study the more long-term appropriation and projects. This paper draws on both our fieldwork as well as the remote observations conducted from Siegen.

Figure 2. CubeTeam (l), 3D modeling (m) and printing (r) in Palestine.

Opportunities in 3D printing

As a general theme, we observed that the playful, collaborative approach to the introduction of 3D printing 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. For example, we observed 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 this way influencing the executing child. The three most frequent categories of projects the children chose were: Names or initials, buildings 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, their representation in other media or the real world (usually a favorite animal). The artifacts displayed a high level of the children's **self-expression**: All 3D models had personal meaning, expressed a story, a fantasy or a wish such as the mosque-inspired building in fig. 3 (top middle) made by Rabi (10) as a *"new house for her family"* – motivated by the poor and cramped living conditions she grows up in.

We generally could observe projects getting more ambitious over time, especially regarding usage of all dimensions. At the beginning, the children treated the building space rather like a 2D canvas, creating merely “brushing” models such as their name with no real complexity in the z-axis, after some time, they started to attempt building more complex structures. Some examples can be found in fig. 3 – 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. 2, middle where a sketch can be seen in front of the computer. The following aspects stood out as beneficial for the success of our project.

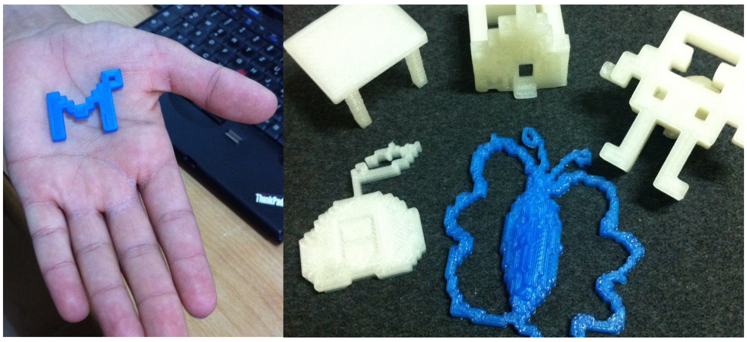

Figure 3. Some sample 3D prints from the field.

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 laughing, joy and beaming faces. There was 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 when we printed out their *“level”*, they were amazed, compared it to the digital version on the screen and all three group members wanted a printout.

Approachable complexity: The children suddenly had the means to create shapes which would have required significant skills, resources and equipment to be made by hand. There was a new degree of freedom regarding self-expression and storytelling through artifacts. An example can be found in the butterfly depicted in fig. 3. This model was built by Nahid, 9 years old, who attended all of our sessions in the camp and was very motivated and curious. She really liked butterflies but was only able to draw them previously, what she frequently did. Through digital fabrication, she is now also able to make her own physical butterfly models that 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 create 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. Wasimah, another volunteer put it this way: *"We now can make things we normally can't"*. At this point, however, we have to emphasize that not the whole 3D printing process proved to be approachable and suitable for children – we will report on the caveats in detail later.

Individualization: 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 names' initials in order to make their creations wearable (see fig. 3, left side). This discovery happened in both camps we worked with independently and each time, it spread quickly by word of mouth as well as over-the-shoulder learning. The children expressed great satisfaction about 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. Nahid, the 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 (transmitted through word of mouth and over-the-shoulder learning). Incidentally, this led the children to discover basic 3D modeling operations on their own in an observably intuitive fashion. They had to apply boolean subtractions in order to cut out their names from other solids. Hadil, a girl of 10, discovered this cutting process first and modeled an apple (depicted in fig. 2, middle) which she later on decided to individualize by adding her name. Notably, all inscriptions were done in Latin letters.

Immediacy and physicality: 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 can make things and that we can print them right now, right here. However, this did never really become an imaginable reality until the first kid tentatively and usually a bit nervously showed us her or his model to 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 turned into 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. Another central aspect which is related to the theme of individualization is that the children really liked being able to *take their prints home*, to show them to their friends and parents and explain how they had created the artifacts and what they meant to them. This led to *conversations* between children and their parents about their activities. These conversations often dealt with the individual artifacts. The 3D printing allowed to bring the individual project results home. In previous projects, e.g. with Scratch, the children simply were not able to show their parents what they had done due to a missing computer and no 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 [to the parents]"*.

Collaboration: As explained, CubeTeam is inherently collaborative in that users can work in the same virtual world at the same models. Most children expressed curiosity about what their friends did and were able to check on their projects directly in CubeTeam. This opportunity generated a certain awareness and had beneficial effects, for instance, starting the popularity of eyelets started as 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. Real time collaboration on the same model in the virtual world did not happen. Instead, the children rather changed or expanded their team structure depending on current interest. For instance, Ruhi (12) changed groups because he did not want to build names anymore but rather wanted to join a group working on a building-like structure. Notably, Gulshan and Nakia, two girls from different camps figured out how to copy models. So, one child would start a model and another would remix it according to their tastes and fantasies. Fig. 4 (r) 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) can be seen in fig. 4 (l). The 3D model itself was downloaded from the Internet but its coloring and the way it was put together was done in collaboration between children and older volunteers. It was inspired by the 2014 escalation of the Gaza conflict and is a testimony to the local conditions.

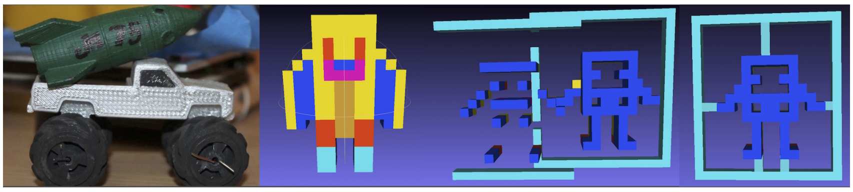

Figure 4. Rocket on a truck (l), Spongebob variations (r)..

Motivation (to come back): The camp children often exhibited *"lack of motivation and distracting behavior"* (Zahid, local coordinator) and *"attend infrequently"* (Aafia). The 3D printing project aroused motivation to come back for the next session, to explore more challenging models and to learn more. For instance, 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 sessions. 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).

Caveats in 3D printing

As already indicated, we also encountered some caveats when introducing 3D printing to the refugee camps. The most notable ones were the following.

Orientation and camera control: The orientation in 3D space for the intended task seems to be very difficult for children. We repeatedly observed attempts of children placing a building block at locations partially 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 with CubeTeam's interface and knew exactly what she wanted to make. However, she needed continuous help from one of the volunteers (see fig. 2, middle for a scene) to figure out perspective and camera control. However, as a counter-example, the group of boys we described above moved with the "WASD"-keys, quite adeptly. This mode is inspired by common controls in ego shooter video games and indeed, when we asked them, they reported quite a lot of experience with such games. Orientation in 3D space was, all in all, quite heterogeneous.

Lack of collaboration and coordination support: As indicated above, collaboration was proved to be a beneficial factor. However, on the tool level, we observed problems with actually supporting negotiation and coordination among the children. It was often unclear who owns or works on which structure. Wasil (13) wanted, for instance, 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 acceptable for them. The only real means for collaboration support inside CubeTeam is a 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 all over the world. He even added these cubes int structures on which other kids currently worked on. This led to frustration, especially by Nahid who was 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.

Construction and limits of current 3D printers: The currently prevalent plastic 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 cannot reasonably be expected to know or understand 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 problem (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 fact that we could print with only 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 problem is caused by the fact that many current 3D printers are constructed openly. So, we had to take care 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. Therefore, at least one of us or the volunteers had to stay near the printer at all times.

Usability and UX issues: We frequently observed problems with the interface for the 3D modeling tool where icons and concepts for certain operations were not understood. Random clicking on the UI until something happened was a regular interaction pattern. More advanced functions, like options to add helper planes, were not used at all. Furthermore, in some instances, children left the world, usually by accident, and got lost in the tool, sometimes even creating a new virtual world containing only themselves from the main menu. These problems 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[5]. Such software requires 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. However, they quickly lost interest due to the high degree of complexity involved and the very technical nature of the tools. This turned our former approach into lectures which did not fit well with the constructionist tone of the project.

Discussion

Apart from hopefully delighting and helping a few children, we were able to find some new aspects on the appropriation of 3D printing in a very particularly structured ICT4D environment. Making as a tool for self expression in marginalized settings seems to be promising and we were able to identify at least some of the aspects which appear to be responsible for this success. Relatedly, we could extrapolate some design implications for future tools for digital fabrication which we will discuss in the following:

The promises

We think it is safe to state that 3D printing and, more generally, digital fabrication constitute powerful and innovative tools for ICT4D, mainly along a broad theme of self-expression.

Playfulness seems immanent to Making and digital fabrication in general which is also confirmed in corresponding literature (cf. Blikstein, 2013; Gershenfeld, 2012). However, this aspect really shines in ICT4D settings where there is a sore lack of ludic engagement. In such settings, we have seen that an emphasis on playfulness helps to work towards continuity in participation and motivation which is otherwise often missing. However, the modeling tools used need to be understandable in their complexity by the envisioned audience. Despite functional shortcomings when compared to more powerful CAD tools, the choice of a toned-down and especially playful tool like CubeTeam works well to help building an appropriation infrastructure (Stevens et al., 2009) in which the children could progress on quickly and iteratively. The aspects of *immediacy and physicality* may be among the most important and lasting ones. Apart from the general social dynamic of learning 3D modeling and printing (slow start, huge motivational boost when seeing your *own* creations being printed), the most central aspect 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 transcend the come_IN club is difficult for the children. 3D

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

printing interconnects the digital with the physical, 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 be generalizable factors influencing the motivation to put work and perseverance in the process of Making as well as in spreading the word.

Another central theme for self-expression is *individualization* through inscriptions or the 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 in Weibert et al. (2014) and other Maker-related contributions such as Kuznetsov and Paulos (2010) who 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. 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 highly industrialized countries where the market relevance of end user innovation has long been announced (von Hippel, 1988) and where we currently see experimentation 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 also 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 a motivational factor. Cases such as the remixing of a model across camps 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, they can make physical items resulting from their virtual collaboration. This effect of collaborative work that breaks the digital-physical boundaries in non- or semi-professional settings also has the potential to scale to much bigger projects such as DIY prosthesis (Krassenstein, 2014).The collaboration aspect of working in the same virtual 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). 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 room, but we suspect that the limitations of the available tools and interfaces to support cooperative work are also relevant factors (more on this below). If we look at collaborations among Makers in a more general sense, we see a significant element of face-to-face collaboration while there are also virtual collaborations which are important for the successes of the movement (Tanenbaum et al., 2013) but there is also : 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. So, a balance between physical and virtual collaborative work seems to be essential. However, there are shortcomings in the currently available ICT for collaboration (Ludwig et al., 2014a). In the following, we would now like to turn towards those tools we worked with in more depth. These toolsets are one of the pillars supporting the work which can be done by Makers and their often problematic design emerged as a central aspect in our analysis:

The obstacles (and what we can do to avoid them)

In a general sense, it is possible to achieve a notably quick learning and understanding process by using available, playful and collaborative tools such as Minecraft or CubeTeam, see e.g. Short and Short (2012). However, there are obstacles and significant gaps in the learning and appropriation processes due to the limitations of those tools as well as the current 3D printer ecosystems. At this point, we confirm and support previous works calling for novel tools and interfaces, such as Willis and Gross (2011). This part of our discussion will focus on implications for design.

Orientation and camera control relates to movement in the 3D space and executing tasks in conjunction with appropriate camera position which is crucial for successful modeling. Therefore, we argue for the inclusion and exploration of alternative ways of navigation: e.g. utilizing 3D mice, which would 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 useful. Some of the children were quite clever in 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 an option. Switches between navigational modes, as employed by CubeTeam, either should be avoided or introduced especially carefully and with appropriation support in mind.

While in Palestine most of the *coordination and collaboration* work happened face-to-face, we see in more long-term projects in Germany that there is a need for advanced coordination mechanisms beyond what is currently available in most playful tools for digital fabrication. Ownership signifiers (such as color or signs) would be worth to be explored. If we turn to the success of voice chat in online multiplayer gaming (e.g. Teamspeak), this line of thought might also be one that could be integrated into collaborative 3D modeling. 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 a problem, especially when supporting novices in their work with complex technologies. It is not surprising that we found many issues, for example relating to modal navigation or less-than-optimal icons in the tools we utilized. Future tools should support a centrally configurable interface in which, for instance, leaving a project could be remotely disabled, or, at the very least, there should be a very simple "bring me to my group" feature. 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) at first and subsequently getting more complex (undo, copying blocks, etc.).

The construction and limitations 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. However, we would suggest to provide a more gentler mode to support the appropriation by making the user aware of why something like a significant overhang probably will not print well. Automated notifications and animations (such as a printing process simulation) might also be ways to supplement this. Similar results and ideas have been proposed in Ludwig et al. (2014a). With other, less restricted, 3D printing technologies which are more affordable (such as laser sintering), this problem might be solved in the medium-term. Furthermore, there is a gap between the ease with which children are able to pick up basic 3D modeling capabilities 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 integrate the the printer, modeling tools, control software and print material to a denser ecosystem. Speaking overly simplified: Offering a *Print-now* button. Actual printers for educational purposes should be designed safer, more encapsulated and should offer basic *it-just-works* settings, based on which exploration can be initiated. Such an approach would positively contrast to 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.

Conclusions and Outlook

We were able to show that 3D printing can be a powerful tool in an educational ICT4D environment. Furthermore, we identified key factors like physical immediacy. Based on our experiences as well as on other Maker projects, we think that our findings are transferable to a certain extent – factors such as playfulness certainly hold true as important for the success of non-professional digital fabrication in other settings (cf. Ludwig et al., 2014a). However, aspects of immediate physicality and the ability to take home printed artifacts have a particular deep meaning and potentially beneficial consequences for settings with marginalized populations. These aspects place Making and digital fabrication into an important position for developmental and educational work with ICT (cf. Mikhak et al., 2002). However, we also saw many shortcomings and caveats such as deficits with tools and interfaces as well as lacking coordination support. These problems hamper (but do not prevent) current efforts with digital fabrication. However, we assume that none of the issues we found was insurmountable or systematic – instead, they represent problems that can be solved by careful and participatory refining and the co-development of tools for digital fabrication (cf. Willis and Gross, 2011). This is a challenge especially geared towards CSCW and HCI researchers and a field we believe to be sustainable and important. While 3D printing is a sensible and currently booming entry point into digital fabrication, other means of Making such as laser cutting or CNC milling (which are all available in more and more Fab Labs and Makerspaces all around the world) should be used and researched in a similar practice-oriented manner. This is a challenge we are currently working on.

In a more macro sense, we discovered that the mediation of physical-digital boundaries was crucially important. It was scaffolded through digital fabrication technologies and moderated by factors such as the culture and value set developed by the Maker movement. These values seem to remain valid and scale for quite different social settings and markets. They prove to be relevant for the work in Palestinian refugee camps but may also be a factor for socio-economic change towards a common- and peer-production based society in other parts of the world – as envisioned by Gershenfeld (2012). In our opinion, investigations into the dynamics of collaborative practices in Making communities and opportunities for their technological support offer a valuable research agenda for CSCW.

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