Break, Make, Retake:

Interrogating the Social and Historical Dimensions of Making as a Design Practice

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Abstract

Making and digital fabrication technologies are the focus of bold promises. Among the most tempting are that these activities and processes require little initial skill, knowledge, and expertise. Instead, they enable their acquisition, opening them up to 'everyone.' Makerspaces and fab labs would blur the identities between professional and amateur, designer and engineer, maker and hacker, ushering in a broad-based de-professionalization. Prototyping and digital fabrication would unite design and manufacturing in ways that resemble and revive traditional craftwork. These activities and processes promise the reindustrialization of places where manufacturing has disappeared. These promises deploy historical categories and conditions—expertise, design, craft production, manufacturing, post-industrial urbanism—while claiming to transform them.

This dissertation demonstrates how these proposals and narratives rely on imaginaries in which countercultural practices become mainstream by presenting a threefold argument. First, making and digital fabrication *sustain supportive environments that reconfigure contemporary design practice*. Second, making and digital fabrication simultaneously reshape the categories of professional, amateur, work, leisure, and expertise; *but not always in the ways its proponents suggest*. Third, as making and digital fabrication propagate, they *reproduce traditional practices and values*, negating much of their countercultural and alternative capacities.

The dissertation supports these claims through a multi-sited and multinational ethnographic investigation of the historical and social effects of making and digital fabrication on design practice and the people and places enacting. The study lies at the intersection of science and technology studies, human-computer interaction, and design research. In addressing the argument throughout this scholarship, it explores three central themes: (1) the idea that making and digital fabrication lead to instant materialization of design while re-uniting design with manufacturing; (2) the amount of skill and expertise expected for participation in these practices and how these are encoded in rhetoric and in practice; and (3) the material and social infrastructures that configure making as a design practice. The dissertation demonstrates that that the perceived 'marginality' of making, maker cultures, digital fabrication allows for its bolder promises to thrive invisibly by concealing other social issues, while the societal contributions of this technoculture say something different on the surface.

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CAD	Computer-aided design
CAM	Computer-aided manufacturing
CNC	Computer numerically controlled
DIY	Do-it-yourself
HE	Higher education
HCI	Human-computer interaction
PD	Participatory design
STS	Science & Technology Studies

Chapter 1.
Introduction

Making and digital fabrication technologies are the focus of bold promises.[1] Among the most tempting are that these activities and processes require little initial skill, knowledge, and expertise; rather, they enable their acquisition, opening them up to 'everyone.' Their advocates hail the way makerspaces and fab labs blur identities—professional/amateur, designer/engineer, maker/hacker—ushering in a broad-based de-professionalization;[2] the way learning-by-doing and hands-on approaches level manual and intellectual work;[3] the way prototyping and digital fabrication unite design and manufacturing in ways that resemble and revive traditional craftwork.[4] These activities and processes even promise to revitalize manufacturing in places where it has disappeared, bringing about it the re-industrialization of urban space.[5]

The promises of digital fabrication, therefore, embody a complicated relationship between past, present, and future. They deploy historical categories and conditions—expertise, design, craft production, manufacturing, post-industrial urbanism—while claiming to transform them. In doing so, they raise important questions: How does history figure in the current practices and discussions on digital fabrication? How do the lived work and experience of practitioners themselves reshape and question the distinctions between propositions and actual conditions? Can these distinctions be given up in the culture of making and digital fabrication, and with what consequences? And in what ways does the work of digital fabrication reinforce long-standing exclusions around gender, race, and class? These questions direct this dissertation.

My argument is threefold. First, I hold that making and digital fabrication *sustain supportive environments that reconfigure contemporary design practice*. These changes include the nurturing of social networks, technical facilities, and financial programs that position maker environments as test beds and springboards in the service of future industrial manufacturing of prototypes and products. Second,

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[1] For an introduction to this line of promises, see Anderson, 2012; Banzi, Cangiano, & Fornari, 2016; Gershenfeld, 2005; Troxler, 2013.
[2] Makerspaces as the sites for interaction between professionals and amateurs, for example, take on a pivotal role for transforming the creative industries where professionals and "the public are initiating new ways" to collaborate according to a report of the British innovation foundation NESTA (Saunders & Kingsley, 2016, p. 4).
[3] On how hands-on practice levels the hierarchies between manual and intellectual work, see, for example, Crawford, 2009; Resnick & Rosenbaum, 2013; Sennett, 2008.
[4] On the aspect of a united workflow, see Sass & Oxfam, 2006; Zoran & Buechley, 2013.
[5] On the potential of returning manufacturing via maker cultures and their impact, see Fox, 2014; A. Smith, 2017; van de Craats & Diez, 2017.

I argue that, even as making and digital fabrication reconfigure professional design practice, they simultaneously reshape the categories of professional, amateur, work, leisure, and expertise; *but not always in the ways its proponents suggest.* They do this, for example, by displacing less technological practices from the entire maker spectrum or downplaying technical expertise required for participation thus delimiting inclusivity and openness to 'everyone.' Thirdly, as making and digital fabrication propagate, they *reproduce traditional practices and values*, negating much of their countercultural and alternative capacities. This takes form in the establishment of institutionalized makerspaces, corporate partnerships, and the removal of political commitment.

As this dissertation will demonstrate, these proposals and narratives rely on imaginaries in which countercultural practices become mainstream. The ambivalent reappropriation of hacking and its ethos in corporate software development or the creation of 'certified hackers' by computer security companies are only two similar examples of how countercultural and alternative practices nourish these imaginaries.[6] In doing so, however, the current practices also rehearse well-established concepts and powerful discourses about education, expertise, production, and creativity, and their relations to design. Making and do-it-yourself (DIY) are generally explored in relationship to different modes of production: from pre-industrial handiwork and craftsmanship through mass manufacturing to post-industrial digital design and manufacturing. New approaches contingent upon craft and hands-on practices situate themselves partially in a historical discourse of handiwork and in the effects of industrial production modes on that handiwork. Further, historical and contemporary developments in computer-aided design (CAD) and computer-aided manufacturing (CAM) show that different influences such as marketing discourse or management conceal the transformation of user agency happening behind the surface.[7]

In following this line of argument, this dissertation presents a multi-sited ethnographic investigation of the historical and social effects of making and digital fabrication on design practice and the people and places enacting it. It is based on four empirical chapters in addition to this introduction and a conclusion. The empirical chapters begin with a comparative analysis of the conceptual foundations of another design paradigm—the historical Bauhaus idea of workshop education—with those of making and digital fabrication. The dissertation then moves to making's

[6] On the multiplicity of hacker practices, see the special issue of *limn* magazine "Hacks, Leaks, and Breaches" edited by Gabriela Coleman and Christopher Kelty (2017). In particular, Rebecca Slayton's and Paula Bialski's essays address this topic in this issue.
[7] On the influence of advertising and management for popularizing these technologies, see, for example, Cardoso Llach, 2015; Downey, 1998; Noble, 1977.

potentials for uniting design and manufacturing and how that translates into abstractions of expertise and skill required for participation. It concludes with an analysis of how mundane infrastructures of making interfere with these potentials.

In order to situate those explorations, the following section introduces more varied descriptions and definitions of making, digital fabrication, and design drawn from popular and scholarly accounts on the genealogy of these practices. It works to locate the ambivalences behind the popular narrative in order to frame the dissertation's research questions and themes. Broadly defined, the central research questions and themes explored throughout the four empirical chapters involve the prospect of uniting design and production, the perception of giving away skill and expertise, and the inconspicuous impact of material and social infrastructures. In the third section of this introduction, I review the significant literature on the emancipatory promises of making and digital fabrication and user participation in technology design, appropriation, and professional work in the fields of science and technology studies (STS), human-computer interaction (HCI), and design research. A final substantive section introduces the methods and field sites, before providing chapter summaries.

Definitions from Making to Design

Making is a catch-all idiom without obligations. The two labels "making" and "maker" became popularized through *Make* magazine and its co-founder Dale Dougherty.[8] A particular reason to choose "making" over "hacking," as he explains, was to demarcate this set of practices and actors, considered friendly and contributive to one's personal and social development, from hacking's more subversive and criminal associations. For Tom Jenkins and Ian Bogost, "It's a deft rhetorical strategy: by construing anything whatsoever as "making," its proponents gain substantial momentum" (2015, p. 30). Making and hacker cultures, however, are intertwined.[9] Both reside in the marginal areas of technology production, have their reputation of "nerdiness," and build upon highly social cultures (Agre, 1997; Coleman, 2013; Turkle, 1984). Making's origins in the hacker ethos are part of a "broader transition from hacking into making" in the product design of information and communications technologies as Silvia Lindtner, Garnet Hertz and Paul Dourish indicate (2014). They note that "[f]ifty years later, we find ourselves in the middle of a new hacker movement that both draws from this

[8] On definitions of making by its famous proponents, see Anderson, 2012; Dougherty, 2012; Stangler & Maxwell, 2012.
[9] The terms *makerspace* and *hackerspace* have been recently included in the Oxford Dictionary (2018). Interestingly, the only difference in the definition to hackerspace is the minor emphasis on a potential focus in computing and technology; thus implying a lineage from hackerspaces.

history and departs from it in significant ways" (ibid., p. 441).

While the subversion of systems and norms appears in maker cultures through the bottom-up participation of users and open knowledge production, these also subvert the principles and infrastructures of computer hacker cultures. Through famous examples such as C-base in Berlin or Noisebridge in San Francisco, and often stereotyped in media representations, hackerspaces strike non-participants as underground and secretive communities that fail to channel their technical abilities and expertise towards social problems. Research shows that this perception is often inaccurate (Coleman, 2013, 2014; Kubitschko, 2015), but the public image of the law-breaching hacker sticks. Makerspaces and other cultivated maker environments likely employ this setting to vindicate their prospective contribution to education by improving technological literacy and lessening the crisis of meaning for the individual. Both issues are deterministically attributed to widespread digital transformations. In response to that, not only the technologically-oriented maker cultures, but also the revival of activities around manual production and craft, propagate certain answers to these matters.

Becoming mainstream and striving for significance, making further attempts to distinguish itself from labels such as DIY and tinkering as both traditionally relate to leisure and hobbyism. The historical development of DIY practices and tinkering revolves around the socioeconomic conditions of a specific period, territory, or class. In the interwar and postwar periods, DIY practices such as home improvement and tinkering with machines proliferated owing to the scarcity of products, economic pressure, and a significant shortage of professionals and craftspeople to perform these activities (Franz, 2005; Kline & Pinch, 1996).[10] Within a few years of financial stabilization in many Western countries, the understanding of DIY and tinkering, as other scholars have shown (e.g., Gelber, 1997; Haring, 2003, 2007; Maines, 2009; Oldenziel, 1997), shifted from means to meaning and from manual labor to manual leisure. Although examples such as ham radio hobbyists illustrate how the practice paved the way for individuals into professional realms (Haring, 2007), DIY and tinkering, in general, are concepts of practice that stand outside professional areas.

The generic character of *making* thus denotes a different material activity than the one practiced by professional designers or by amateurs only. It suggests a new category to represent those transgressing the boundaries between professionals and laypeople. Making, as Evan Barba suggests, is "a form of design rhetoric" which has different understandings and goals (2015, p. 638). Following

[10] Historically, DIY was also actively promoted on a governmental level, for example, through the "Make Do and Mend" program initiated by the British Ministry of Information during World War II.

Janet Vertesi (2014b), making is like the "seams" for identity: rather than someone being simultaneously a maker and an amateur or a maker and a designer, it defines the common ground between them. Likewise, I found that digital fabrication creates a hybrid space between making as an amateur undertaking and manufacturing as a more professional one. *Digital fabrication* advanced through the downscaling and democratization of the respective industrial manufacturing technologies and processes.[11] In theory, the term only describes the popular computer numerical control machines (i.e., CNC mill, laser cutter, 3D printer) and the required CAD and CAM techniques used to program and control them.[12] But it further implies a continuum from design to manufacturing that evokes the possibility of uniting these separated activities. I return to this idea throughout the dissertation questioning its fulfillment on several scales—personal, procedural, technological—by reviewing theoretical accounts and contemporary observations. Therefore, I apply the term *digital fabrication* to label this set of popular practices and technologies, while *making* denotes a broader range of hands-on practices contributing to the design of artifacts.[13]

Although making and digital fabrication encompass a broad range of activities and technologies, my study focuses on two main groupings. First, technologies and activities concentrated around electronics and computing such as different microprocessors (e.g., Arduino, Raspberry Pi, Beagle, etc.), electronics kits (e.g., littleBits), design of printed circuit boards (PCBs), and user experience (UX)/user interface (UI) design are grouped as *prototyping*.[14] While some of these root in industrial research and development and manufacturing processes, their direct lineage is less apparent than the second type. A second set of activities and technologies, grouped under the label *manufacturing*, consists of typically advanced industrial technologies and processes on the principles of computer numerical control (CNC) such as additive manufacturing (i.e., different forms of 3D printing), subtractive manufacturing (e.g., laser cutters, CNC mills), and textile technologies (i.e., knitting machines, looms). As my research unfolded, my analytical focus shifted towards the group of manufacturing maker technologies and practices to reflect their relationship to design as defined above.

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[11] The word 'digital' is added to denote the transition from data stored on punch cards and tape in early CNC machines to digital files in recent CAM technologies (Bohne, 2013).

[12] CAD refers to the use of computer systems to support the creation, modification, and analysis of a design in the form of digital files for different manufacturing processes. CAM represents the application of software to control machines, thus relating to early numerical control (NC) programming tools.

[13] While these two groupings of technologies and practice have come to represent maker culture, making and maker participation cover a wider range of distinct material practices that are not confined to these only (see Rosner, 2018).

[14] The list of prototyping technologies is long. Arduino, however, remains the emblem of do-it-yourself maker cultures (Hertz, 2011; Lindtner et al., 2014).

Craft as well is paramount to maker discourses.[15] By framing different practices of making and digital fabrication as craft (and craftwork), these become positioned along established communities of practice respected for their proficiency in particular areas. Moreover, craft presupposes a complete workflow from design to production executed by the same person (Dormer, 1997; Risatti, 2007). The framing also emphasizes that although the fabrication technologies define most of the outcomes, making materializes through the power of the human hand (McCullough, 1996). Craft as a parameter, therefore, works to bestow agency upon makers. In fact, until the eighteenth century, craft with its guilds structure invested in power and secret knowledge described a form of politics and not a specific way of fabricating things (Dormer, 1997; Lucie-Smith, 1981; Scott, 1998). Possibly unsuspecting of this early definition, contemporary maker cultures instead relate craft as the opposition to mass manufacturing processes and products. Compared to mass manufacturing with tried out standards and methods, making and digital fabrication like craft manifest processes contingent upon ad-hoc decisions and imperfection (Tsaknaki & Fernaeus, 2016).

Design, on the other end, shows an explicit connection to the developments of industrialization and "the arrival of an economy with highly structured divisions of labor" (Fry, 2014, p. 13). Yet, similar to making and digital fabrication, design also finds appeal in craft's values—dedication to material, appreciation of workmanship, and the unity of mental and manual labor (Rees, 1997; Walker, 1988). While there is some disagreement about a precise definition of design, for Walker (ibid.), a few manifestations prevail regardless: as a process (the practice of designing); as the result of that process (a design, a model, a prototype); as manufactured products; or as their appearance. One can see how this set of manifestations expands on the relationship to industrial manufacturing. While I consider these definitions in this project as indispensable, in the burgeoning debates about what design is and who designs, they delimit design to a predominantly Western conception that emanates from the capitalist demands of industrial production.[16] In this dissertation, therefore, I follow HCI scholars Seyram Avle and Silvia Lindtner (2016) in their articulation that design as a process and practice for the making of artifacts simultaneously produces identities, status, and capital.

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[15] For intersections of craft, making, and digital fabrication, for example, see, Bean & Rosner, 2012; Cheatle & Jackson, 2015; Pérez-Bustos, 2017. For compelling accounts of the history and practice of craft concerning identity formation, utopian paradigms, and object making, see also Adamson, 2007; Forty, 1986; Schwartz, 2013; Sennett, 2008.

[16] Discussions on the dominant Western conceptions of design, in particular, as a practice of professionals have been questioned from within and outside the design disciplines. For an early critique, see the work of Victor Papanek (1972). Recent examples include the communal forms of infrastructure building as design (Ewart, 2013); hackathons as modern-day 'humanitarian' manifestations (Irani, 2015); and a vision for "autonomous design" to create sustainable social orders (Escobar, 2018).

Research Questions and Themes

This dissertation lies at the intersection of STS, human-computer interaction (HCI), and design research, with a subject matter simultaneously historical, contemporary, sociological, and philosophical. In addressing my argument throughout this scholarship, I seek to explore three central themes: (1) the idea that making and digital fabrication lead to instant materialization of design while re-uniting design with manufacturing; (2) the amount of skill and expertise expected for participation in these practices and how these are encoded in rhetoric and in practice; and (3) the material and social infrastructures that configure making as a design practice. The dissertation addresses these intertwined questions and themes throughout the empirical chapters.

Materializing design and uniting it with manufacturing. The materialities of making and its emphasis on democratized access to industrial manufacturing technologies indicates the possibility to materialize design concepts into physical products immediately. This promise originates in design's divorce from fabrication and manufacturing contingent upon a delegation and division of labor initiated with industrial production. Computational tools for manufacturing create a linking environment between design and manufacturing. The recent phenomena explored in this dissertation promote a reorientation of manufacturing agency to makers, designers, and everyone participating in them. They promise to connect the virtual world of design with the material world of manufacturing. In doing so, this dissertation asks: *How are digital fabrication technologies enabling this materialization and thus uniting design with manufacturing? And who is to become 'whole' by embracing the full process of production?*

Expertise and skill. Developers and proponents of maker cultures invest much rhetorical effort to suggest that skill and expertise are not prerequisites for the participation in technology design and production. Indeed, as the evolution of products in the maker economy with the increasing 'kitification' in electronic prototyping or the full automation of 3D printing implies, their user and potential maker can instantly start off tinkering. At the same time, participation in the cultivated environments and practices for making foreshadows a line of expert-like principles of knowledge validation and dissemination. Practices and technologies that appear as undemanding are often blackboxed in the codification of technical knowledge. On that account, *which type of expertise is at work in maker environments? And what configures skill-based 'maker' expertise?*

Infrastructures of/for making as a design practice. In the emancipatory and technosolutionist program, making and digital fabrication employ technologies, machines, and physical spaces as their infrastructures to build upon them. These infrastructures are embedded in already existing social values and real environments. The latter enact an effective integration of these 'novel' cultures and practices. Mundane infrastructures such as entrances, signage, or the geographical location that bring off making and digital fabrication to the broader audience tend to be overlooked in their influence. However, these often shape the initial interaction with these cultures even before any actual fabrication. *What other infrastructures besides technologies are at play in maker cultures? How do they construct the interaction with the cultivated environments for making?*

Theoretical Background

In this section, I outline the two main bodies of literature that helped begin with my research and address the proposals of making and digital fabrication. The first set of studies examines critical research on making and digital fabrication in HCI, social sciences, and design research. In the second body of scholarship, I summarize analytical approaches and studies in STS on user participation and appropriation of technology and the role of material practice and experience in professional work. The literature review presented here is limited to these aspects. It situates the project and I add relevant theoretical reflections in the empirical chapters where needed, with each chapter providing a condensed literature review related for its argument. In the second chapter, I discuss the prevalent theoretical positions on the Bauhaus and how those helped establish its distinctive place in design. Chapter Three analyzes different visions of materialization of design and its uniting with manufacturing through CAD/CAM technology. The fourth chapter summarizes different conceptions of expertise and the encoding of gender. In the fifth chapter, I bring in theoretical discussions on material and social infrastructure. Finally, this theoretical section ends with an exposition of how reading design as a discrete discipline through STS troubles the dominance of design's paradigms and how my project contributes to such undertakings.

Making and Digital Fabrication as Democratizing Design and Technology

The practices, technologies, and communities for making, hacking, DIY, and craft have been of growing interest in the fields of HCI, design research, education, as well as the social sciences. In particular, HCI finds value in making and maker cultures as these trouble the traditional concepts of design, production, and use through with their structural component of user participation (Williams & Irani, 2010). As Silvia Lindtner, Shaowen Bardzell, and Jeffrey Bardzell suggest, "making challenges whether there is (or needs to be) a gap between designers and engineers on the one hand, and between designers and end users on the other" (2016, p. 1398). Analyses on making and digital fabrication reference a range of subject matter in their efforts to situate them within established cultures and systems of technology design and production: the different motivations for making; the characteristics of communities and their cultures; the recognition of lay practice; the emancipatory promises of maker cultures for user empowerment and participatory citizenship; a critical assessment of the rhetoric of technosolutionism and the expanding hegemony of globalizing franchises for making; down to the influence of craft and the actual material practice of making. In the following, I discuss several literatures on these subjects that inform this dissertation. Structured in the order above, it suggests an imaginary wayfinding from what attracts one to making in the first place to what problems arise as one becomes immersed in these cultures.

Several studies have investigated the motivations behind making and digital fabrication (e.g., Davies, 2017; Kuznetsov & Paulos, 2010; Phillips, Silve, & Baurley, 2013). By acknowledging the countercultural origins and the DIY ethos of maker practices, these studies suggest that making appeals to people for its possibility of self-actualization and for its non-commercial orientation. Meanwhile, cultivated physical environments for making, whether that is a shared machine shop or a fab lab in a public library, also attract people with their programs for gaining literacy in digital technologies and processes (Foster, 2017).[17] Understanding the motivations behind the participation in making, maker cultures, and digital fabrication also requires an exposition of the geographical and economic context of individuals (Tanenbaum, Williams, Desjardins, & Tanenbaum, 2013; Lindtner et al., 2016). Moreover, we need to differentiate between a pleasure-oriented and a utility-driven DIY practice if we want to understand ideas of democratization, innovation, and the difference between professionals and lay makers as Garnet Hertz points out (2011). While these examples help situate the emancipatory objective of making, they leave out a differentiation between prototyping and manufacturing technologies and how that relates to emancipation. This, in particular, resides in their research focus on individual makers, smaller communities, and cultivated maker environments rather than on a connection to existing structures for (technology) design and production.

Studies on characteristics of communities for making and their cultures also draw upon ethnographic research of single shared machine shops rather than comparative multi-sited examinations (e.g., Hielscher, 2017; Kohtala & Bosqué, 2014). Their insights therefore often overlap.

[17] The term 'shared machine shop' was first used by Karl Hess in his book *Community Technology* (1979) to describe communal workshops for tool sharing. It became applied to maker cultures in the special issue of the *Journal of Peer Production* 5 (2014). I use the term interchangeably to makerspaces, fab labs, and hackerspaces.

Other examples, however, highlight a critical broadening: for example, a study on the UK-based Men's Sheds under the scales of making illustrates the role of open workshops in public life beyond innovation and peer education (Taylor, Hurley, & Connoly, 2016);[18] the emergence of feminist hackerspaces challenges the technosolutionists norms of maker cultures (Fox, Ulgado, & Rosner, 2015; Toupin, 2014); or, Chinese maker communities challenge the "conceptual binaries of design as a creative process versus manufacturing as its numb execution" (Lindtner, Greenspan, & Li, 2014). These perspectives allowed me to evaluate dissimilar projects across my field sites which were focused on social contributions rather than design innovation. Making, maker communities, and maker culture, therefore, designate distinct instances not always sharing the same value system (Bardzell, Bardzell, & Ng, 2017). As scholars, we need to recognize the dividing line between the subtlety of culture and the observable practices of making (ibid.).

In recognition of the differences, a few studies in design scholarship on non-professional design and its relationship to professional practice ask to ennoble lay and amateur practice (e.g., Atkinson, 2006, 2010; Beegan & Atkinson, 2008; Pacey, 1992; Raff & Melles, 2012). These design scholars argue that recognition is not about equating but putting this alongside and in dialogue. DIY practices and "digital tinkering" demonstrate that clear-cut boundaries around professional and non-professional design cannot be retained (Beegan & Atkinson, 2008). For Atkinson, making and digital fabrication move design towards a more inclusive "post-professional era," which gives agency to non-professionals through participation without making the others obsolete (2010, p. 138). Others have argued that while DIY making precipitates the blurring of clear lines between professionals and amateurs, it also fosters the recognition of time, dedication, know-how, and experience involved in the production of "something good" by amateurs (Kuni, 2014). While these studies argue for a 'recuperation' of amateur and lay perspectives, other scholars have explored the parallel development of strategies for the professionalization of maker practices. Some examples include the integration into hardware startups and incubators (Lindtner et al., 2014) and the popularization of hackathons as means for job acquisition in tech and design industries (Irani, 2015).

Arguably, both interpretations demonstrate possibilities for emancipation through making and digital fabrication. Yet often the emancipatory prospect tends to emphasize its contribution to marginalized individuals only. In *FabLab: Of Machines, Makers and Inventors* (2013), Carstensen describes the function of fab labs as doubtless political: "FabLabs have a clear mission to empower people to

[18] Men's Sheds are communal workspaces for older men to mitigate mental health concerns (see Taylor et al., 2016).

participate and engage in technological development and to educate underprivileged people" (p. 61). Such accounts have been questioned on the state of DIY making by several special journal issues and conference panels.[19] Technology appropriation and open source hacking provide a role for participatory citizenship and the potential emergence of user innovation. As scholars on making and hacking have emphasized, however, such political endeavors also often imply a level of expertise and knowledge about access to these activities and communities that is likely concealed by popular rhetoric (Powell, 2012a, 2016; Ratto & Boler, 2014; Roedl, Bardzell, & Bardzell, 2015; Smith, Hielscher, Dickel, Söderberg, & van Oost, 2013). In her investigation of 3D printing's "political imaginaries," design scholar Jesse Adams Stein (2017) notes that it is essential to understand how such rhetoric around emancipation, empowerment, or economic revival become deployed and unquestioned social norms. I take up these contentions between rhetoric and the actual state of making in *Chapter 3* and *Chapter 4* where I follow different projects around reviving manufacturing and their translation into expertise.

As uncritical pieces of literature fill the shelves of bookstores and help reinforce the position of the Maker Media franchise and the Fab Foundation, a critical scholarly assessment of the rhetoric of technosolutionism and the hegemony of these globalizing franchises takes issue with those characterizations (e.g., Carelli, Bianchini, & Arquilla, 2014; Hunsinger, 2017).[20] An early account of the multiple facets of technological utopianism inscribed in *Make* magazine problematizes the absence of attention to political responsibility (Sivek, 2011). *Make* magazine's assertive emphasis on self-actualization through technology aligns it with corporate interests rather than citizen empowerment (ibid.).[21] Thus, not only do making and maker cultures "suggest something different" (Bardzell et al., 2017) but the rhetoric of making also differs from its reality. In applying the metaphor of a "sandbox" to making, while the surrounding grass lawn represents established practices and professional cultures of technology production, Jenkins and Bogost argue that maker technologies create their ecosystems instead of actually opening up the blackbox of technology and thus enabling access to that (2015).

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[19] Several HCI scholars had put up a panel on the contradictions between the emancipatory narrative and the actual state of maker cultures (see Ames et al., 2014). The *Journal of Peer Production 5* (2014) dedicated a whole issue questioning the myths of the maker movement. Further, as I finish writing the dissertation, the *Journal of Peer Production* launched their latest issue 12 (2018) on the institutionalization of shared machines shops within universities and corporations. The journal *Digital Culture and Society* also dedicated a special on making and hacking (2017) and their co-constitutive practices.
[20] Besides publications such as instruction guides on maker technologies and processes, a few others fill the shelves of uncritical and popularizing non-fiction that subjugates to the norms and values of the maker movement and the Fab model. See, for example, Gershenfeld, 2005; Walter-Hermann & Büching (eds.), 2013; Menichinelli (ed.), 2017.
[21] Hertz (2012) has critiqued *Make* for presenting the Natalie Jeremijenko's "Feral Robot Dogs," a political artwork and pedagogical project, in the inaugural issue, while later maintaining a completely apolitical focus.

These literatures above contributed to querying the emancipatory promises of making and digital fabrication and to building a research framework for this dissertation. In doing so, however, they provide limited descriptions on the actual material practice, workflows for digital fabrication and their implications, and the influence of craft as both practice and line of thought (Bean & Rosner, 2012). A few studies in HCI and design investigate the explicit relationship between making and design practice (e.g., Cheatle & Jackson, 2014; Rosner, 2012; Vallgarda & Feraneus, 2015). Amy Cheatle and Steven Jackson's (2014) study of the Wendell Castle studio has been formative for my understanding of the organization of design and fabrication of objects with CAD/CAM technologies and CNC milling as well as for an entanglement of social theory, design research, and material practice. Daniela Rosner's (2012; 2018) constructive work in HCI on weaving, knitting, bookbinding, which crosses the boundaries of the digital and the physical as well as of craft and technology, reinforced my framing of this contemporary phenomenon and design in historical terms. Similar to their work, following the accounts of craft theorists David Pye and Peter Dormer, other comparative studies between traditional craft and digital fabrication question the appropriation of craft methods within these discrete and automated technologies (Loh, Burry, & Wagenfeld, 2016; Taylor & Townsend, 2014). I return to the idea of wholeness within the discrete and automated digital fabrication processes and the promise it brings to unite design and manufacturing throughout my empirical chapters.

Users, Machines, Interactions: Perspectives in Science and Technology Studies

Critical scholarship on making and digital fabrication helps trace out the emancipatory propositions put forward by its proponents. An investigation into the social and historical dimensions of making as a design practice, however, would be incomplete without the critical framing provided by the interdisciplinary trajectory of STS. The following review is limited to analytical approaches and studies that resonate with a democratization of technology. The intersectional nature of this project, in part, centers around two groupings: (1) studies of users which have allowed scholars to expand the traditional emphasis in STS outside the professional context of scientists and technologists; and (2) examinations of how human-machine interactions define work and practice. By addressing the emancipatory project of making and digital fabrication, this theoretical framework allows for a careful analysis of maker cultures and digital fabrication in the direction of my research questions. Further, it presents the area of knowledge to which my work contributes.

In the 1980s, several strands in the sociology and history of technology shifted the focus onto the role of users to compensate for the deterministic and linear accounts of technological design and development. One approach, known as social construction of technology (SCOT), derived from the sociology of scientific knowledge (SSK), historical studies of the development of large technological systems (Hughes, 1983), and labor relations (Noble, 1977). As a multi-directional model, SCOT focuses on variations and selections in the development of technological artifacts by inquiring into the "relevant social groups" that shape a technology's formation. Relevant social groups signify groups with a shared meaning for a specific technology and not just its users (Bijker & Pinch, 1985, 2002; Pinch & Bijker, 1984). Closely associated with Wiebe Bijker and Trevor Pinch's analytical work on the bicycle development in the late 1800s, the approach paved the way for understanding user agency. Early work within SCOT, however, has been criticized for its strong emphasis on the initial design and development phase and its absence of diversity (Mackay & Gillespie, 1992; Williams & Edge, 1996). In particular, the critique highlighted the failure to consider post-design appropriation by users, which, for example, Ronald Kline and Trevor Pinch reprised later with their study of the technology modification of North American farmers (1996). Moreover, the choice of a relevant social group for analysis is contingent upon the researcher's preference and therefore potentially problematic (Humphreys, 2005).

SCOT has also come under criticism for failing to account for the place of marketing and especially ideology of designers and engineers in technological development as Mackay and Gillespie (1992) illustrate. In particular, the effect of ideology is important to consider in the interaction of maker cultures and professional design as none of these seems impartial to preconceptions about their potential roles in shaping society. This aspect gets further expanded through Madeleine Akrich's concept of "scripting" user actions, capacities, or intentions into technical objects by their designers (1992). Scripting deduces particular positions, namely the designer's perspective, about the interplay of technology and society. Feminist histories of technology diversified the perspective on users as well. Historians of technology drew attention to consumer and household technology and the role of its users, mostly women, as active participants in defining the design. Shifting perspectives not only in terms of agency but also of context proves beneficial as studies on household technology (e.g., Cowan, 1983, 1987; Mohun, 1999; Parr, 1999) and the complex incorporation of communication technologies into everyday life demonstrate (Silverstone & Hirsch, 1992; Silverstone & Haddon, 1996).

A particular research focus has been on the appropriation of standardized technology by users. Kathleen Franz's example (2005) of early Ford Model T female drivers at the beginning of the twentieth century shows how tinkering empowered them to minimize the imbalance between their desires and the standardized technology. Standardization of production and of the final product, here, also served as a catalyst for tinkering.[22] Through appropriation consumer technologies are modified to match a situation at hand (Corn, 2011). Appropriation for reuse marks a more radical form through adjustments that extend the designers' intentions. Necessity prompted North American farmers in the interwar period to converge automobiles into farm vehicles or power stations (Kline & Pinch, 1996). Yet closure mechanisms through the stabilization of the design, for instance, by the inclusion of many user-suggested improvements in later designs become irreversible as Bijker contends (1999). As research on technology appropriation and SCOT's endless possibilities through "interpretive flexibility" suggests, closure and stabilization become difficult to achieve (Cowan, 1987; Williams & Edge, 1996). In fact, computer technologies hint towards a permanent destabilized state maintained for different reasons by both users and producers.[23]

The category of technology-oriented and product-oriented movements (TPMs), introduced in the work of STS scholar David J. Hess (2005; 2016), proposes an analytical concept for addressing the interactions of bottom-up and decentral user collectives such as maker cultures with established systems of technology production. TPMs represent a coherent subcategory of the general concepts of social movements and collective action. However, compared to the latter, TPMs focus less on political action but rather on creating and disseminating alternative forms of material culture with their objectives often linked to private-sector activities (2005, p. 56). Through a comparative analysis of three TPMs on open source, renewable energy, and nutritional therapeutics, Hess deduces three hypotheses on their effects. First, the strong emphasis on technology and innovation aligns the goals of TPMs with corporate stakeholders through a seemingly cooperative relationship ("private-sector symbiosis" hypothesis). Second, established industries begin to absorb developments by the TPMs making those resemble existing technologies to serve corporate profitability ("incorporation and transformation" hypothesis). Third, following the actions of the prior two hypotheses, conflicts between traditional social movements and industries begin to occur (hypothesis of "object conflicts"). Indeed, his examples illustrate the different stages and modifications of their objectives they undergo. The ethical goals of the open source movement, for example, remain potent; yet much of its results and products found application in proprietary computer technologies. This approach provides a valuable framework to address issues of co-option and mainstreaming found in maker cultures. Drawing on STS studies of the social development of scientific and technical networks (e.g., Bijker &

22 As historian Rudi Volti (1996) exemplifies, American cars more than their European equivalents, allowed for easy disassembly and reassembly through the use of interchangeable parts.

23 See, for example, on the development of a "parasitic systems" by employees to enhance their work Bossen & Dalsgard, 2005. Further, Greenbaum & King, 1991; Kyng & Mathiassen, 1997.

Law, 1992; Callon, 1986; Hughes, 1987), Hess justifies this particular takeover of technologies by corporations as ways for those to become powerful. As such, his concept is beneficial to raise more reflective questions about what defines success in a social movement. As he points out, narrow concepts of success make original visions of alternative practices and movements disappear, but they also open new areas of conflict that could lead to diversification of TPMs, their technologies, and practices.

Various studies have demonstrated that other practices such as hobbyist tinkering with electronics grant agency to users to modify stable technologies (e.g., Haring, 2007; Oudshoorn & Pinch, 2003; Takahashi, 2000). Moreover, some of them emphasize the significance of users' ability in technology appropriation for repair, maintenance, and other technical work (e.g., Edgerton, 1999; Denis & Pontile, 2015; Jackson, 2014). Kristen Haring's historical account of ham radio culture notably reveals the dual identity that amateur ham operators turned to depending on their situation—hobbyist and skilled professional in the field of electronics at the same.[24] The scholarship on repair and maintenance cultures of electronics from radios through TV sets to personal computers further illustrates the role that hands-on practice played to understand how the technologies worked. Through hands-on manipulation with hardware components, early users of the TRS-80 desktop microcomputer learned how to assemble it and keep in service (Lindsay, 2003). The development of computer science as a discipline and the affiliated industry, however, indicates the neglect of hands-on material practices as forms of design (Nakamura, 2014; Rosner, 2018).

While the first body of literatures addresses the material interactions between the 'normal' user and technology, the second set of studies indicates the importance of material hands-on practice in everyday professional work in science and technology, including engineering companies (Bucciarelli, 1994; Henderson, 1998; Vinck, 2003), technical service (Barley & Kunda, 2004; Orr, 1996), laboratories (Latour & Woolgar, 1979; Traweek, 1992), or architectural studios (Yaneva, 2009). Classified often under the rubric of repair and maintenance, these practices remain sidelined by the significance assigned to design and development, whether that is industry, policy work, public debate, or research. As Julian Orr writes, "when one is discussing the work with those who manage it, what they talk about is rarely the same as what one has observed" (1998, p. 439). Although 'normal' users of technology also practice repair and have to maintain their artifacts, research involves primarily

[24] Radio repair opened up many opportunities for men to work in electronics research and for the military. See, for example, Douglas Engelbart, An "Oral History: Interview 1," in the series "Stanford and the Silicon Valley," Judy Adams and Henry Lowood (interviewers), Thierry Bardini (editor), 1987.

professional users. As such, these studies have been helpful to blur the distinctions between understandings of technology actions such as use, appropriation, maintenance, repair, or design, as well as give nuances to the hybrid identities that human actors inevitably acquire through machine interaction, whether or not these get recognized (see Haring, 2007; Jones-Imhotep, 2012).

Situated in a contested ground between workplace studies, organization studies, anthropology of work, and STS, Orr's investigation of photocopier technicians' work practice *Talking About Machine* (1996) might not have been the first study of human-machine interactions in work environments. But it changed the focus of attention from those with power—scientists, designers, engineers, managers—to the social groups that make their professional environment possible. Drawing on Latour's thesis that technology actively shapes society (1991), Orr's ethnography illustrates the dynamics of handling a triangular relationship among technicians, customers, and machines. As representatives of each group are situated differently, conceptions of technical work and repair as standardized knowledge disseminated through manuals and descriptive documentation fall short. Orr's work had been influenced by Lucy Suchman, a Xerox PARC-colleague, and her counter-position on planned action in AI development (1987; 2007). In her ethnographic account, she emphasized the ways in which AI designers, based on the idea that planning and goal definitions precede human action, fail to reckon the ordinary ways that people use to accomplish their work. Plans for them are but one of many possibilities, not the defining one. Instead, plans are better understood, as she adds, as rhetorical devices for explaining actions. The situatedness of human-machine interactions, and thereby human to human interactions, dependent upon social and material conditions becomes limited at any moment if actions are prescribed by designers and the machines they manipulate.[25]

In Orr's account, plans take the form of descriptive manuals and documentation of the copiers provided to them to solve issues. However, as he analyzes technicians employ a mix of socially distributed resources contingent upon their situation: narrative about success and failure shared in their specific community of practice over lunch meetings, coffee breaks, or in hallways, tacit and kinaesthetic knowledge, as well as manuals. The plurality of possible situations implies that what is taken-for-granted, namely fixing broken or maintaining functional technologies, becomes a form of 'un-scripted' design. By 'un-scripted,' I mean here the opposite understanding of Akrich's "scripting" performed by designers. To follow Herbert Simon ([1969] 1996) if design, in general, is an activity that produces a course of action, then technicians face micro-design situations on a day-to-day base

[25] Planning has been criticized within AI for the absence of a response to situatedness and improvisation that define human action (Agre & Chapman, 1990; Brooks, 1991).

that un-script what the designers of these machines and their manuals define. The activity becomes a negotiated organization of material and social practices (Voskuhl, 2004). Henderson's ethnographic study of the introduction of early computer graphics in design engineering follows Orr's idea of socially distributed resources in work practice (1998a). Studying draftspeople in the transition from working on paper to working on a screen, she argues that many developed either situated mixed practices or a "different-use practice" by choosing context-based tools to cope with the different changes. The ways the practitioners I observed in shared machine shops focus on situated material knowledge, collective experience, but also machine limitations have connections to these ethnographies of professional work. My engagement with this conceptual work helps to clarify the reliance upon situated standards and experiential knowledge not only for approaching making and digital fabrication as a novice but also for the routinization of these practices and processes.

Significance of the Study: Reading Making and Design with STS

Research on the commons and borderlands between design and STS is relevant to account why this recent phenomenon provides favorable conditions for design. After all, design itself invites STS to study its material practice and epistemology. In the tradition of the Design Methods Movement associated with the early work Christopher Alexander (1964) and John Christopher Jones (1970), design constitutes a "third culture" along science and technology to draw upon a synthesis of scientific, technical, and social knowledge (Cross, Naughton, & Walker, 1982). Its dawn as a profession and epistemology is closely connected to concepts and techniques such as codification of practical knowledge, standardization of methods, boundary demarcation between distinct epistemologies and communities of practice, and the institutionalization of science and technology. These concepts and strategies have been explored extensively in STS. While design's development after World War II suggests a synthetic and conceptual nature of practice, prior to its separation from manufacturing it became intertwined with experimental and material practice.

Within the history of science, for example, studies on material experimentation in the practical arts demonstrate how these influenced intellectual work (P. Smith, 2012; Valleriani, 2017). For instance, Steven Shapin and Simon Schaffer (1985) famously discuss how Robert Boyle's theoretical argumentation depended upon his practical experimentation and handwork in his public demonstrations. Early Renaissance artisans and artists shaped the work of natural scientists and thereby distorted the binary categories of artisan vs. scholar or mental vs. manual work (Long, 2011; 2017). Long's argument that a binary classification of types of individuals and their practices simplifies "when in some arenas the two moved closer together, communicated, and adopted each others practices" (2011, p. 9) accounts for the heterogeneous collaborations I observed in my fieldwork. In particular, it offers a provocative understanding of skill-sharing initiatives and peer learning between individuals with different backgrounds upon which the operations of makerspaces depend.

STS as the study of knowledge construction through science and technology is contingent upon an understanding of processes, the entanglement between mental and manual work involved in them, and their situated perspectives. "Thinking in terms of processes rather than properties, it becomes clear that what values are materialized and how they are made visible are deeply intertwined issues," argue Houston et al. (2016, p.1412). Following Donna Haraway (1988) and Lucy Suchman (1987; 2007), design processes appear in specific situations by exposing particular positions and individual point of views. Herbert Simon, design theorist, Nobel laureate, and RAND consultant, once stated that "[e]veryone designs who devises courses of action aimed at changing existing situations into preferred ones" ([1969] 1996, p. 111). Widely cited, his definition of design and who designs, however, was not meant to be inclusive. Like maker cultures, design draws upon dominant paradigms. If making and design, however, want to embrace openness and acknowledge 'everyone,' this requires challenging their conceptual frameworks, for example, by taking up STS' focus on controversies, multiplicity, and the socio-political implications of technology as Daniela Rosner (2018) proposes through her "critical fabulations." In reading design with STS and interrogating the social and historical dimensions of making and design, this dissertation project makes a modest attempt in this direction.

Previous research on making and digital fabrication in information and design studies provides detailed analyses and descriptions of making's background in technological work as well as their practitioners' motivations. It also indicates how different material practices inform technical work. More recently, several studies in sociology, feminist, information and media studies have taken up the questionable visions of maker cultures to democratize and subvert traditional technology design and blur the boundaries between professional and amateur by looking at ongoing developments such as the growing institutionalization of makerspaces and the alignment with professional processes of making.[26] This dissertation adds to these discussions by interrogating the idea of "de/stabilizer" of boundary categories which this contemporary phenomenon implies. At the same time, researchers in STS have begun to intersect with critical research in design and influence each others' methodologies.[27]

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[26] See, for example, the *Digital Culture and Society* special issue on making and hacking (2017); *Journal of Peer Production* special issue on institutional makerspaces (2018).

[27] For example, the *Design Issues* special issue edited by Woodhouse & Patton, 2004; the 2014 STS Italia conference "A Matter of Design: Making Society through Science and Technology" aimed at connecting the interdisciplinary areas of

These projects expand the core STS scholarship on design from its meaning as a prescribed form or action that shapes user interactions with the social environment (e.g. Latour, 1992; Suchman, 2007; Winner, 1986) to design's "social worlds" (Volonté, 2015)—its epistemologies, practices, expertise, but also demarcation strategies. Following the call to inquire into the social worlds of design, this dissertation further contributes by bringing in conversation the existing scholarship in STS and design research on similar themes and problems.

A Multi-Sited and Multi-Modal Ethnography of Making as a Design Practice

This dissertation employs a qualitative methodology that combines an ethnographic survey and a critical historical analysis of the relationship between making and design. To capture a picture of this "technoculture," as Anne Balsamo (2011) describes the myriad of recent participatory digital phenomena, the dissertation presents a multi-sited ethnography through the concurrent study of distinct but related field sites. The concept of multi-sited ethnography, as anthropologist George Marcus (1995) writes, developed in response to empirical phenomena that occur across multiple times and spaces. Their prominence in the interdisciplinary fields of science and technology studies, feminist studies, and cultural studies requires multiple layers to break with the conventions of ethnography as "a relatively long term […] stay in a field of choice" (Falzon, 2016, pp. 1-2). Multi-sited ethnography asks to follow the actions, connections, and relationships between people, things, ideas, and systems not just over time but across space (ibid.). Attaining to this interpretation, this dissertation employs the qualitative methods of interviewing, participant observation, autoethnography, document analysis, and archival research.

The project follows the methodological practices introduced in the study of scientific laboratories in the 1970s (Knorr Cetina, 1981; Latour & Woolgar, 1979; Traweek, 1992). This foundational set of ethnographies had effect on later studies that broadened its concept—from engineering design companies and their practices (Bucciarelli, 1994; Henderson, 1998a) via their practitioners and the interfaces that configure their work (Downey, 1998; Orr, 1996; Yaneva, 2009) to the broader significance of a global "technoculture" such as free and open software (Kelty, 2008). These studies informed both methodologically and theoretically my dissertation. In particular, Kelty's account of free software development, which has no specific geographic location while remaining

design and STS. More recently, a special issue in *Diseña* 12 (2018) looks at pedagogical experiments between design and STS.

dispersed through different empirical sources, illustrated how to vindicate my selection of data (ibid., p. 19). Following his example, multisitedness applied here enables us to interrogate a comparatively similar phenomenon from different perspectives and scales.

Interviews and participant observation helped to understand how making and digital fabrication redefine and contribute to design as a process and practice. To collect broader accounts on questions of participation, users, skills, and expertise, I conducted and recorded digitally interviews with community members engaging in different roles. The formal and informal interlocutors range from founders to technical managers, from designers to educators, from students to retired engineers and people seeking to adopt new work practices, and from employees to volunteers. Many of them represent "lead users" (von Hippel, 1986) by being positioned close to critical research and development trends. For participant observation, my activities varied from being immersed quietly in the daily business of these places, attending machine training sessions and different group meetings, and watching making processes between humans, technologies, and the surrounding environment. The approach of participant observation suggests a quiet and unobtrusive observation of interactions. However, in studying the practices and technologies of a participatory phenomenon such as making and digital fabrication, participation becomes inevitable. Collins and Pinch's concept of "participant comprehension" (1982), therefore, offers a more acceptable description of a research method in which "the participant does not seek to minimize interaction with the group under investigation, but to maximize it […] [where] the development of native competence may be the end point of participant comprehension" (ibid, p. 61). Developing near-native competence of the researched field while maintaining a level of surprise is also what defines a 'good ethnography' in STS according to David Hess (2001).

Fieldnotes and photography documented interactions and material infrastructure. An autoethnographic approach to this study through adopting and experimenting with the technologies themselves compensated for a frequent absence of 'everyone.' An expanded document analysis connected the experiential accounts of my interlocutors and observations with popular narratives on requirements for expertise and skill, the materialization of design, and the potential prospects of relocating manufacturing back to where design occurs. Together with the ethnographical data, these methods grounded how different definitions and categories of expertise reflect historical accounts. Archival data, limited to the Bauhaus, contextualized the prevalent and in part paradoxical ideas about non-expertise, de-professionalization, or re-industrialization, put forward by maker cultures, in the traditions of (professional) design education.

The fieldwork conducted between May 2016 and January 2018 builds the thrust of this dissertation. The empirical studies included nineteen sites across six countries and twelve cities.[28] Nine sites provided the principal cases elaborated in the empirical chapters, while the remainder supports the research questions. The *principal* ones in this dissertation became, in the order of their first visit, Happylab (Vienna), OpenDot (Milan), WeMake (Milan), Fab Lab Torino with Arduino (Turin), Machines Room (London), Fab Lab Berlin, Happylab (Berlin), Fab Lab Munich, Underbroen (Copenhagen), and MAKLab (Glasgow).[29] The *ancillary* field sites include Maker Austria (Vienna), MakeWorks (Toronto), InterAccess (Toronto), MakerLabs (Vancouver), FabLabDresden, Makerversity (London), Labitat (Copenhagen), Urbanlab (Nuremberg), Haus der Eigenarbeit (Munich), and MakerSpace (Garching/Munich).[30]

Some of these sites I identified via online search on platforms such as *wiki.hackerspaces.org* and *fablabs.io*, whereas others were introduced to me via my interlocutors and scholars. The initial contact with five of the principal field sites came through mutual connections who collaborate closely with these spaces.[31] The remainder I approached directly via email contact based on research and in connection to other activities such as conference trips. In some instances, the fieldwork and conversations with my interlocutors led to my referral to contribute as an "expert" to non-academic projects.[32] The representation of these places as being open to 'everyone,' while at the same time pursuing professional objectives of different kinds, determined the choice of field sites. Taken this aspect into consideration offered an initial ground of contestation to observe. While the apparent focus on Western and North European locations overshadows the perspectives and voices of more marginal geographies, I chose to study them for their principal role in shaping different European

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[28] The countries in alphabetical order are Austria, Canada, Denmark, Germany, Italy, the United Kingdom through England and Scotland.

[29] As a franchise, I consider both Happylab locations as one field site.

[30] For confidentiality purposes, I use pseudonyms for my interlocutors although they waived anonymity. In a few cases, this is impossible due to the public appearance of some. This includes online or offline publications, their participation as presenters and experts at public or other networking events, with this information being available on websites or other media. Interlocutors whom I have identified as public figures are referred to with their real names. Although some of the other interlocutors appear on the websites of their associated makerspaces as staff members or residents, I chose to change their names as long as they have not commented publicly on topics related to making and digital fabrication. The chosen pseudonyms are random but reflective of the person's identified gender. As diversity in gender, as well as race and age, falls short among many shared machine shops, I omitted using gender-neutral names to represent the persistently low numbers of female participants. I do not intend to identify in any section real names from pseudonyms.

[31] I share mutual acquaintances with these field sites, i.e., WeMake, OpenDot, Fab Lab Turin, Fab Lab Berlin, and Underbroen.

[32] One of FabLabDresden's founding members referred me to one of their colleagues for the application for public funding for a Precious Plastics' installation. At Happylab Berlin, for example, one of technical manager asked me to comment for a newspaper article on their recent launch.

maker-related initiatives from a continental offshoot of the Fab Cities networks to active and completed EU-funded research initiatives.[33] The practice of networking, institutionalizing, and building professional associations that become visible from the outside suggests a trend towards embedding these places and practices into established social norms of work and production.

The majority of field sites have a particular emphasis on design practice such as forms of product and industrial design, computer interaction design, and architecture. However, for example, InterAccess' intent leans towards providing artists with access to new or obsolete electronic technologies. Haus der Eigenarbeit as a publicly-funded social initiative sees its role in-between being a "third place" (Oldenburg, 1989) and an affordable location for low-income residents to re-skill for the job market. Both also stand out as being the longest-running shared machine shops without interruption among my field sites, while the remainder are relatively new having been around for about four years on average. Sites such as Haus der Eigenarbeit, InterAccess, or FabLabDresden, I included for their diametrical objective and communities compared to professional places such as Makerversity in London or MakerSpace Garching. Supported by international tech corporations, the latter two aspire towards an innovation-driven model of design and collaboration with little contribution to local residential needs. MAKLab as a charity, the Copenhagen hackerspace Labitat, or the hybrid co-working space MakeWorks, each with distinct intents and governance, have broadened this multi-sited ethnography to avoid the reproduction of homogeneous patterns of sampling. In part, I included them for the opportunity to build a sample related to the question of returning urban manufacturing. This sample included the four cities Berlin, Copenhagen, London, and Milan, each with two sites, and Glasgow as the central place from which MAKLab had planned to develop a redistributed network.[34] More detailed and context-specific accounts of my field sites are provided in the four empirical chapters.

The data collected from my fieldwork at these sites amounts to ninety-five hours of participant practice observation, eighteen formally recorded semi-structured interviews with a total length of fifteen hours, and around twenty-five hours of informal conversations and interviews. The latter were not recorded digitally but through field notes. In some cases, interviews were arranged in advance with my interlocutor with pre-distributed broader questions about the site's history, governance, members' structure, and skill acquisition. Pointed questions, for example, on particular CAD/CAM processes,

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[33] Notable examples include Bianchini et al., (2014), *Makers' Inquiry (Itali*a); Rosa et al. (2017), *Overview of the Maker Movement in the European Union*; UCL's annual *Institute of Making* report; the *MAKE-IT* project funded by the EU Horizon 2020 program that concluded in early 2018; and more recently, the *Cities of Making* report (2018).

[34] To great despair for its members, MAKlab announced insolvency in summer 2017.

the lack of diversity in maker cultures, or questions of demarcation between professionals and amateurs were asked based on my assessment of gained trust and also comfort to talk about critical topics. My interlocutors often responded openly and attentively to critical positions on the questionable blurring of professionals and amateurs, issues with gender, and even my expression of disapproval of the co-optation of maker principles by corporations and institutions. Interviews were recorded when possible during breaks or after closing hours to accommodate their busy and tattered work schedules since some of them held simultaneously several positions—designers, educators, and machine shop staff. Yet, with technical managers or support staff, interviews could sometimes be interrupted by members and makers having problems with machine and questions.

The limited number of interviews further reflects an issue specific to the professional orientation of these sites, namely that of the restricted availability and time on my interlocutors' end. A traditional immersive ethnography seemed unattainable. For the designers among them, these sites are not just laboratories for experimental practice. Rather they represent a flexible option to having a studio without actually renting one; thus sharing expensive facilities while also accessing social expertise immediately. While maker cultures evoke a picture of persistent tinkering and entertainment, for many of the professional designers a day could be spent entirely with working up logistical tasks on their computers, in phone and email communication with clients and contractors, or in different meetings. Spontaneity and responsiveness to my interlocutors' work commitments defined my empirical research.[35] As Marcus comments, "[i]n conducting multi-sited research, one finds oneself with all sorts of cross-cutting and contradictory personal commitments" (1995, p. 113). However, qualitative research is also beginning to create burdens and disapproval in some of my sites as requests by researchers increase due to the topic's popularity; yet research results rarely meet the sites' expectations.

While interviews and participant observation composed the major part of the multi-sited ethnography, I also conducted autoethnographical research based on my experience with learning different digital fabrication practices and processes. Autoethnography regards "personal experience as an important source of knowledge in and of itself, as well as a source of insight into cultural experience" (Ellis & Adams, 2014). My reflexive process began before the data collection for the dissertation.[36] Becoming familiar with the technologies and practices allowed me to retrace the

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[35] In one instance, for example, one of my principal field sites had forgotten our arrangement for my follow-up visit. Their belated realization, only by chance, led to a short-notice cancellation of pre-booked travel on my end.

[36] This data defined my initial research questions and laid the foundation for the project. For three years before the proposal approval, I gathered observations and insights from four Maker Faires and festivals in Toronto and New York

structure of CAD/CAM processes and to substantiate interactions between hands-on and tacit knowledge. For Garnet Hertz, "doing something yourself, as a non-expert," though perhaps easy, provides a valuable insight into how things work that we often take for granted, but also through moments of unease caused by this interaction (2012, p. 8). Technology and media studies engaged with their systematic changes to social norms require an understanding of their technical working (Kittler, 1999). My autoethnographic approach thus focused primarily on developing a technological literacy through practice.

For this reason, I participated in five distinct machine training sessions for about twenty hours, respectively one in laser cutting and one in machine sewing, and another three in CNC milling. These were in addition to machine training sessions that happened during participant observation. The experience of learning hands-on informed my analysis of required expertise and skills not only for the operation of these machines but for participation in maker practice. While personal experience guides autoethnography and allows to interpret cultural experience, other principles such as insider knowledge or reclaiming voice could define this approach (Ellis & Adams, 2014). Besides training sessions, I widened the personal perspective by preparing a critical making workshop on smart infrastructure. I was invited by the research project "Smarter Together" at the Technical University in Munich to develop this electronic prototyping workshop for its project stakeholders, which included a group of about twenty local policy-makers, university students, social scientists, and residents of the particular neighborhood. This learning-by-doing of different technologies regardless of my position as student or tutor diversified the perspectives on expertise, skill acquisition, and accessibility that I had deduced from the other empirical data. The process of autoethnographic research recognizes the experience of confusion, uncertainty, and discomfort, and permits to use it as data (Berry, 2006; Richardson, 1994). Although beneficial for understanding a technical process, being familiar and close with the research field also bears problems such as neglecting mundane details or treating them as irrelevant when they are not (Orr, 1996; Wilkie, 2010).

Critical document analysis supplemented the data from the multi-sited ethnography. First, it focused on promotional and informative material issued by my field sites. This included descriptions

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City. I also attended two 3D printing and CAD workshops. At one of them, I provided training for children. My experience in preparing workshops builds upon the design of how-to instructions for a DIY assistive technology based on Raspberry Pi developed at the GaMaY Lab at York University, and a workshop for a maker festival based on that. Further, I have attended several presentations on digital fabrication and music technology hackathons. Practical knowledge in electronic prototyping was developed in a graduate course in critical making at the University of Toronto. Finally, my skill-based knowledge would be remiss without the one-and-half years spent at the Fabrica Lab at York University, directed by Edward Jones-Imhotep.

of their objectives, activities, and updates on their websites, newsletters, blogs, social media channels, and also printed brochures and handouts. Textual and visual analysis of these documents invites to see how these sites shape their public perception through a specific language and imagery that seems to remove technical sophistication from many of the maker activities. Second, I surveyed for seven months a weekly online conversation on Twitter called #MakersHour launched in summer 2017. The format following a question and answer format increased the heterogeneity of maker identities included in this study—from mostly professionals to deemed 'amateurs.' Third, with the increasing diversification and growth of maker cultures, research projects on policy regulations of peer-to-peer production, citizen science, and possibilities for reindustrialization have been initiated in the United States, the European Union, and China.[37] Some of these projects included makerspaces and fab labs as their research partners. The produced white papers and reports on developments and trends were analyzed for how maker cultures and digital fabrication are measured regarding success and what societal benefits are attributed to them based on the studies' empirical data.

In conjunction, I conducted approximately forty-five hours of observation and participation in various formal and informal events related to making and digital fabrication. Although maker cultures and digital fabrication have become a focus of many academic conferences, these are rarely attended by active members of these communities. Instead, members' focus remains on talks and workshops at Maker Faires, the annual FAB meeting organized by the Fab Foundation, or other local variants of these franchises. Hence, I participated in five full-day maker-related conferences with a heterogeneous audience that included shared machine shops managers and staff, policymakers, politicians, business strategists, activists, scholars, and different kinds of makers. In following Clifford Gertz's definition of "thick description" (1973), anthropologist of craft and work Alicia Ory DeNicola and Clare Wilkinson-Weber (2016) emphasize that looking at insider and outsider accounts of advocates, in their case in craft, such as producers, designers, consumers, and policy makers, deepens the cultural context.

Two of the attended events were conferences organized by an independent research institute in Berlin with a focus on sustainable economy—"The Transformative Power of Makers" (March 1, 2017), and "Workshops of Societal Change" (October 25, 2017). The other three events were less formal gatherings. The Maker Assembly in Edinburgh (March 3, 2017) was part of a series of events co-organized and funded by the British Council that aim to start a critical discussion of maker cultures.

[37] For example, the British innovation foundation Nesta commissioned a study of makerspaces in China and their contribution to innovation (Saunders & Kingsley, 2016). Further, the Cities of Making report published in 2018 reflected on opportunities and challenges for redistributed urban manufacturing based on studies in the cities of London, Brussels, and the metropolitan region of Rotterdam and The Hague.

I also joined the hands-on production day with presentations and workshops at the annual gathering of the association of open workshops in Nuremberg, Germany (November 9, 2017). The last one titled "Coworkers, Makers & Hackers: True Opportunities to Renew Work Practices & Entrepreneurship?" took place in London (January 18, 2018), and was organized by the Research Group on Collaborative Spaces. Further, more informal but very focused formats included: a day-long design hackathon (Disrupt Disability, London) and a presentation (Made for My Wheelchair, Berlin) on the possibilities of digital fabrication for the production of assistive technologies; a half-day workshop on making and open approaches for social innovation run by the DSI4EU project at the premises of Underbroen, Copenhagen; a workshop on designing CAD tools at the interdisciplinary laboratory "Image Knowledge Gestaltung" at Humboldt-University in Berlin; and a 3D printing ceramics demo and workshop with artist-potter Jonathan Keep in Berlin.

Archival research on workshop practice in design education as attributed to the Bauhaus school and its intellectual foundations was conducted at the Bauhaus-Archive in Berlin in February 2016. While providing historical background, this research also revealed how a dominant paradigm of design has been redefined and has reappeared in the current instantiations of makerspaces and fab labs. Following historian of science Orit Halpern who "consider[s] history as a matter of densities and probabilities rather determinist relations" (2014, p. 36), I applied a historical analysis onto a contemporary phenomenon to reassess how narratives and ideas can become instrumentalized as labels for originality and innovation. During different visits of my field sites, I further supplemented the empirical and archival data with parallel visits of over ten art, design, and science exhibitions that approached the topics of DIY, craft, making, digital fabrication, and design from a multitude of perspectives. A complete overview with a rationale of the connection of each exhibition content to dissertation themes is included in Table 1.

My coding of the data followed the themes of my research questions. I coded iteratively throughout the fieldwork, which meant that themes and propositions changed over its course. The initial set of themes looked carefully on the binaries of 'amateur/professional' and 'work/leisure.' While these remained relevant for the dissertation, more intricate codes were revealed as on-topic through iterative analysis as well as the addition of two themes which I recognized in conversations and in theoretical research during the fieldwork (Becker, 1998; Emerson, Fretz, & Shaw, 1995). One relates to the idea of returning production, while the second concerns the relationship between automation through CAD/CAM workflows and the promise of controlling the process by a single person and technology (Cardoso Llach, 2015; Downey, 1998). The latter struck me as corresponding to Bauhaus' intent of implementing craft and workshops in design. Elements of these themes encompassed the analysis of types of skills and knowledge required to participate, levels of details in training sessions, availability of different resources, visibility of personal and professional connections, community building, visions of and for maker cultures, and how these were brought up and communicated in interviews, informal conversations, and other activities. Following Adrian Smith who argues that "[t]he open innovation agenda simply wishes to insert makerspace creativity into global manufacturing circuits under business as usual" (2017, p. 14), my research shifted towards understanding how structures and categories, which makers nevertheless disapprove of, become reproduced as making and digital fabrication expand in different directions.

Exhibition Title	Context	Date	Location
XXI Triennale "21st Century. Design After Design": Making is Thinking is Making: New Korean Craft; New Craft; Call Under 35	Interaction between new technologies, processes, materials, and established design and craft practice	11 September, 2016	Various locations, Milan, Italy
True Value by Theaster Gates (temporary)	Relationship between city development and making	12 September, 2016	Fondazione Prada, Milan
London Design Festival 2016: electrocraft.show; Fix Your City, Machines Room; Engineering the Future (Digital Design Weekend)	Value of handcraft in the design of electronic technologies; role of citizens and maker-spaces in the transformation of city life	21–23 September, 2016	Various locations, London, UK
Wave: How Collective Ingenuity Is Changing the World (temporary)	New participatory and collaborative paradigms for social innovation	1 October, 2016	Maker Faire Berlin, Station Berlin
#Creative Production (temporary)	Creative processes from prototypes to products	7 October, 2016	Retune Festival, Berlin
Do It Yourself Design (temporary)	History of DIY practices from World War I to recent phenomena	16 October, 2016	Bröhan-Museum for Arts and Crafts, Berlin
Object Sessions. The Story of Material Education in 8 Chapters (temporary)	History of material-based pedagogies	19 October, 2016	Museum der Dinge, Berlin
+ultra. knowledge & gestaltung (temporary)	Relationship between human design processes, design in nature, and technical processes	23 October, 2016	Martin-Gropius-Bau, Berlin
Craft and Design exhibition (temporary)	Historical and contemporary exchange between craft and design	7 March, 2017	Craft Professions Fair, Munich
Bauhaus: Craft Becomes Modern (temporary)	Historical and contemporary exchange between craft and design	30 June, 2017	Bauhaus Dessau
Digital Design Weekend, London Design Festival	Exposition of contemporary digital art and design	23 September, 2017	Victoria & Albert Museum, London
Designer-Maker-User (permanent)	Interplay of the three identities	18 January, 2018	Design Museum, London

Table 1. Overview of art, design, and science exhibitions included in the research.

Chapter Outline

In the following *Chapter Two*, I situate my empirical work in the context of workshop-based design education as notably connected to the Bauhaus school of design. I hold that the historical project of

Bauhaus provides a useful starting point for analyzing how the contemporary movement of making and digital fabrication develops. In relation to my research questions, this chapter presents how the Bauhaus promoted an idea of craft-based workshops for mass-manufacturable prototypes as unconventional. It frequently concealed its contingency upon preexisting conditions and practices of work, education, and social order. Thus, the chapter draws on a comparative analysis between the Bauhaus and the studied contemporary phenomena illustrated through fieldwork data. It explores how inconsistencies and revisions involving ideas of craft, technology, and skill become harnessed to advance their different objectives.

In *Chapter Three*, the analysis follows the prospects that making and digital fabrication put forward for design practice. Broader articulations highlight the opportunity to materialize design within a technology or a process and unite it with manufacturing as well. These propositions suggest unity on a personal level by empowering users through access to fabrication means, on a technological level by automating the CAD/CAM process, and on a geographical one in articulations such as the revival of urban manufacturing. The chapter juxtaposes these expected connections of design and production expressed in different strategies of my field sites with an analysis of the technical intricacies of becoming competent in the CAD/CAM workflow through various maker course offerings. Attending to how the idea of unity gets rearticulated in the histories of CAD and CAM, this chapter explores the subtle differences between the prospects and the actual unfolding of digital fabrication. Further, surveying how technical training translates into an integrated CAD/CAM workflow alludes to questions of anticipated expertise and knowledge.

Chapter Four characterizes the inconsistent configurations of expertise in DIY maker and digital fabrication cultures. Following the preoccupation with non-expertise as both entry point and condition to the prosperous impact of maker cultures, I delineate the discrepancies about forms of expertise. I explore expertise within maker cultures through the relationship to skill and experience, practices of legitimation, and their social embeddedness in technical practices and cultures. Through different perspectives including distant unidentified makers, my interlocutors, and my experience in learning CNC milling, the chapter discusses how maker cultures cultivate implicit notions of expertise that are local, skill-based, contingent and situated. I concentrate on the concepts, metaphors, and knowledges practitioners employ in the performed practice. Looking at particular indications from this set of data, I question the idea of empowering 'everyone' through making with a discussion of the implicit gendering of technical skills.

Chapter Five examines the infrastructural effects of making and digital fabrication. It studies how mundane elements of material and social infrastructures such as entrances and spatial organization interfere with the rhetoric of openness and democratization of technology production that backs maker cultures. In reviewing snapshots from my fieldwork, I demonstrate how different aspects of infrastructure rendered in maker environments translate into the reproduction of conventional norms and power asymmetries instead of resulting in potential "alternatives." Infrastructures as methods of classification selectively include and exclude. At the same time, this chapter aims to illustrate how different activities happening around my field sites work to break the cycle of reestablishing customary norms and categories.

In the *final chapter*, I conclude by summarizing my argument and the central findings of each empirical section. I connect how each dimension of making and digital fabrication described in the empirical chapters relates to the main propositions within maker cultures and design. I also interpret how these dimensions reproduce or unsettle the dominant narratives of technological production and design expertise. Instead of proposing that making is a best practice for design and accepting that as a norm, I consider its implications for people and practices pressed on the margins by the dominant discourse.

Chapter 2.

Parallels Do Not Meet:

Crafting Democracy at the Bauhaus and in Digital Fabrication

> Now, if one was founding a new Bauhaus—a new place where people build—for the early twenty-first century, […] what might that look like? A place where art, craft and design can engage with the post-industrial age, and with educating a new kind of artist or craftsman or designer or all three who in turn can flourish within a post-modern society and culture […].
>
> —Christopher Frayling, 2011, p. 133

> Value is that place between existing conditions and a desired state.
>
> —Dietmar R. Winkler, 2001, p. 56

Almost a century after its foundation, the Bauhaus school remains a symbol of Modernism renowned not only for its 'radical' pedagogy in art but for its contribution to the foundation of a novel profession, namely industrial design. The Bauhaus represented many things at the same time: an institution, a "forge," a prototype, an idea, a style. Despite its short-lived existence from 1919 to 1933, when it was pushed into closure by the political regime in Germany, the philosophies underpinning the Bauhaus lived on. The forced emigration of many of the leading Bauhaus figures—the directors Walter Gropius and Mies van der Rohe, the teachers and artists László Moholy-Nagy, Josef Albers, as well as students and later educators Anni Albers, Gunta Stölzl, Herbert Bayer, and Marcel Breuer—ensured the survival of Bauhaus ideas such as connecting art to technology and industry, craft-based workshop practice, and of its specific design pedagogy in later art and design schools across continents. These ideas also surfaced in the aesthetic and manufacturing approach of, for instance, furniture giant IKEA (T. Smith, 2016, p. 145).

Likewise, the Bauhaus resonates with contemporary practices and technologies of digital fabrication as Christopher Frayling's quote suggests (2011). Frayling's post-industrial and postmodern vision of a 'new' Bauhaus evokes present-day accounts of what do-it-yourself (DIY) maker cultures and digital fabrication are promising to realize. Without allusion to making and digital fabrication, he proposes that technologies such as rapid prototyping would enable people in art, craft, and design to situate themselves professionally (ibid., p. 136). In Frayling's understanding, that means being prepared for industrial production in general (ibid.). The Bauhaus professed a similar idea. Among the prospects seen in DIY maker cultures and digital fabrication, a repeated one is about personal empowerment through access to a set of small-scale manufacturing technologies and processes. Gaining this access would allow not only the group of people described by Frayling, but 'everyone' to move closer to professional production. Narrating the idea of technology access as a question of social status plays a strategic role in DIY maker cultures, but also for design schools in the tradition of the Bauhaus. In fact, its prominent idea of uniting art and industry through craft, and later through technology, manifests itself in one of the DIY maker cultures' broadest tropes—that of everyone seizing the means of production by affording their access. Frayling's suggestion, therefore, stresses a set of questions. How did the Bauhaus strive to integrate questions of craft, art, and design? What framed those attempts as part of the Bauhaus' larger political enterprise? Also, how do these insights about the interrelation of making and politics transfer onto our contemporary post-industrial age?[38]

This chapter's goal is to examine the related visions of both, the Bauhaus project and that of digital fabrication, by exploring how each valued craft and its relation to technology. Despite their apparent differences, the Bauhaus and digital fabrication share an instrumentalization of craft and its embodied practice. To illustrate this, I focus on two critical elements of the Bauhaus pedagogy: the "preliminary course" and the workshop, and their correlation to the procedural and political domains of craft, technology, and industry. The preliminary course and the workshop were built around both material and social technologies—manual skills, machine infrastructures, and manufacturing standards, but also the hierarchical authority of the school's faculty, guild and industrial associations, and interpersonal relations. By reconstructing these foundational elements of the Bauhaus model historically, I elucidate how maker cultures and digital fabrication deploy a similar politics of craft fabrication. These connections have been unexplored to day. This reconstruction illuminates a particular moment of design's professional development that attempted to oppose the ultimate separation of manufacturing from design. Making and digital fabrication undertake a similar effort towards design practice. As such, this parallel examination appears as particularly apposite to my field sites which have a strong focus on design practice shaped by design's institutional development (Findelli, 2001).

On that account, my argument is twofold. First, I argue that the specific political positionality of the Bauhaus influenced the broader conception of design education and practice. As such, I draw

[38] The approaching Bauhaus centenary in 2019 has stirred a reexamination of the sociopolitical relevance of its ideas. A recent research symposium titled "Preliminary Course: From Bauhaus to Silicon Valley" echoes the reassessment of Bauhaus ideas for present-day developments. This event linked the Bauhaus to the global sites of ICT corporations, widely treated as the epitome of creativity and innovation, by asking if these "advanced laboratories of computer, internet and media companies represent the Bauhaus of the twenty-first century." Retrieved from http://www.projekt-bauhaus.de/en?themes=preliminary-course-from-bauhaus-to-silicon-valley .

attention to the Bauhaus's inward, or interpersonal conflicts, and its outward politics, such as the dictates of industry, administration, and the public, and I consider how those politics were taken advantage of by the school and some of its representatives (Winkler, 1994). Instead of marrying craft to art as declared in its Manifesto, the Bauhaus instrumentalized craft and technology to categorize design as an ameliorated art. This acted to maintain art's privileged status over craft. Second, I hold that by understanding the historical project of Bauhaus and its political economy of design, provides the groundwork for understanding the development of the contemporary movement of digital fabrication. It captures the pretentiousness of the Bauhausian idea of framing the workshops as 'laboratories for prototypes for serial production'—a model that relies on many levels on preexisting conditions and practices of work, education, and, in general, social order.

The chapter's structural method is comparative, but it draws its comparisons by highlighting specific inconsistencies represented by the Bauhaus. The chapter begins with a brief analysis of the existing scholarship on the Bauhaus followed by a description of my methodological approach through an analysis of primary sources.[39] The focus of historical scholarship on the school's pedagogical model, its programmatic emphasis on the workshops and craft, and its vision of connecting design to manufacturing, acts to foreground recurring ideas of making and digital fabrication and their expression among many of my study's empirical cases. In the section that follows, I set the Bauhaus in sociocultural context by looking at the location of the school, the core elements of the curriculum, the objective of industrial partnerships, and, finally, how the Bauhaus Manifesto reproduced the hierarchical relationship between art and craft.

This contextual background is then particularized with the analysis of three constituent Bauhaus ideas, which allow for a parallel assessment of the Bauhaus and the "emergent" sociotechnical developments of maker cultures and digital fabrication. First, it indicates how the historical call to level the hierarchies between artists and craftspeople responds to the comparable proposals of maker cultures to blur the boundaries between professionals and amateurs. Second, the rejection of specialization in practice *qua* professionalization at the Bauhaus is similarly reproduced in the recent culture of open peer production. Third, the Bauhaus vision of workshops as laboratories for industrial prototypes and its difficult achievement foreshadow how making and digital fabrication are contingent

[39] These sources include the writings of leading Bauhaus figures: founding director Walter Gropius, preliminary course originator and artist Johannes Itten, and masters László Moholy-Nagy, and Josef Albers. Hereafter upon repetition, I will use the shortened version of Moholy-Nagy's last name, that is 'Moholy.' This name is found in many primary and secondary sources. Further, to avoid confusion with his wife Anni Albers, I will abbreviate upon repetition Josef Albers as 'Albers' and Anni Albers as 'A. Albers.'

upon established sociopolitical and economic frameworks. The exposition of the Bauhaus context and its three constitutive ideas demonstrates how the contemporary making phenomenon is likely full of inconsistencies, revisions, and negligence of the past. To draw this comparison, in the penultimate section, I weave in these historical insights in three references from my empirical data: a vignette from a recent exhibition on contemporary and historical craft at the Bauhaus Dessau; an investigation into students' participation in makerspace activities, and two contemporary maker-developed "prototypes for serial production." The chapter concludes with a discussion of how a backward reading of a recent phenomenon reveals contradictions.

Significance of the Bauhaus: State-of-the-Art

The earliest scholarship on the Bauhaus, strongly influenced by the works of Herbert Bayer (1938), Sigfried Giedion (1954), and Rayner Banham (1960), credited the personalities and opinions of Gropius, Itten, Klee, Kandinsky, Moholy, and Albers for transforming art education, thus creating the design disciplines, without questioning critically the sociopolitical context behind that. The overall positive perception of the Bauhaus model as influential for design education still resonates with contemporary research. For instance, Nigel Cross (2007) argues that foundations of design education can be traced to the Bauhaus and, in particular, Itten's preliminary course, who encouraged a 'bricolage' approach in training. Ellen Lupton and J. Abbot Miller describe the focus of their collection of visual research as being "rather on the Bauhaus and design theory" (1991, p.2). Other scholars have also highlighted the influence of the Bauhaus model, that is the blurring of disciplinary and practical boundaries between art, craft, design, and architecture, and how that informed design pedagogy in Europe, the United States, and Latin America (Findeli, 2001; Julier, 2017). However, several scholars of design history, craft research, and visual studies have instead argued to give more attention to some of the neglected aspects of the Bauhaus instead of revising the celebrated histories of a few Bauhäusler (Forgács 1995, 2016a; Schüler, 2013; T. Smith, 2014).[40] Marginalized accounts include broader questions of gender (as the Bauhaus being one of the first art schools accepting women), the workshops and the craftspeople involved in them, the work of students, their precarity, and their anonymous presence imposed through school regulations and funding, the interactions with the local public and environment, and the school's place amongst Germany's industrial complex.

[40] A few studies have taken the lead to close this gap: for instance, Éva Forgács's examination of conflicts and politics (1995; 2016a), the survey on the masters of craft by Ronny Schüler (2013), and, more recently, the work of T'ai Smith on the Bauhaus weaving workshop and feminism (2014).

Discursive Methods

My initial research focus on the Bauhaus centered on various writings produced by the aforementioned Bauhäusler before, during, and after their tenure at the school.[41] I explored primary records such as personal documents, lectures, handwritten notes related to the development of the Bauhaus's preliminary course, the workshop training model, and reflections on the relationship between art, craft, and industry. The latter constitute the conceptual work of Gropius and have shaped vitally the school's tenet. I took the preliminary course as my starting point for the archival research at the Bauhaus-Archive in Berlin. Although the preliminary course takes a central position in much of the scholarship, especially for design education models, I shifted the focus slightly during the analysis of the collected material. My concurrent fieldwork and the coding suggested a new framework broadening the topic of education. As a result, my revised framework ascribes the notion of craft as the mode of production and the rendition of the workshop as a laboratory for prototypes for industrial manufacturing as conditionals for the Bauhaus grand narrative, albeit those leaving an opaque legacy as the Bauhaus scholarship suggests.

Shifting the analytical perspective on the collection, I kept the material on the preliminary course as ancillary data. It serves as a means to understand how the preliminary course was used towards the goal of developing prototypes for serial production at the Bauhaus. Another reason for keeping a secondary focus on the structure and philosophy of the preliminary course is that it revealed one of many conflicts at the Bauhaus. Throughout its brief existence, the Bauhaus remained in a state of flux as its multiple shifts and conflicts reveal. Many of them revolved around the figure of Gropius. The particular conflict I refer to is the one of functionalism in the context of art, evident in Gropius's and Moholy's rational approaches. For as long as the pedagogy was guided by art from a purely aesthetic and idiosyncratic perspective as Itten's understanding of art education emphasized, it could not achieve the goals that Gropius had with and for the school. Gropius's position on the functions of art changed over the years of his directorship but also before and after that. Writing in his essay "Zeichnen und Werktätigkeit" (Drawing and Handiwork; 1918), for example, he insisted on the relevance of drawing and handiwork skills for art as well as for the children's education and development. Counter to his later positions on *l'art pour l'art*, here perhaps strategically as an establishing move and to accentuate the novelty of the school's structure, he emphasized an unrestrained approach—an idea

[41] I will be using the German word *Bauhäusler* when referring to multiple members (directors, teachers, staff, and students) of the Bauhaus school.

that came to represent much of Itten's pedagogy.

In fact, the workshops served an instrumental and thus a rational function for the Bauhaus. Together with craft, they built the instruments of the Bauhaus grand narrative from their earliest mention in the Manifesto to their actual realization in the Dessau school building. They attracted funding from the government of Saxony-Anhalt and partnerships with the local industry. At the same time, their instrumentality depended on several factors. First, the geographical location of the school—Weimar or Dessau—played a pivotal role in the possibility of local alliances.[42] Second, the aspect whether the school was accommodated in a building that met their infrastructural needs. Third, each Bauhaus director in turn—Gropius (1919-1928), Hannes Meyer (1928-1930), or Mies van der Rohe (1930-1933), determined the school's artistic, political, and economic orientation. Finally, the person responsible for the preliminary course—Itten (1919-1922), succeeded by Moholy (until 1928) and Albers in collaboration, epitomized the spectrum from art over craft to technology with their respective pedagogies. Ultimate constellations of location—director—instructor like, for instance, Weimar—Gropius—Itten or Dessau—Meyer—Albers created different interpretations of workshop operations and production of manufacturable designs.

This discursive analysis of the conflicting and marginalized Bauhaus accounts of leveling the hierarchy between art, craft, and design, the denial of specialization, or the idea of workshops as laboratories for mass-manufacturable prototypes deconstructs its popular representations. At the same, it helps to situate the contemporary myths of making and digital fabrication as overturning the structures of design and technology production.

Historical and Theoretical Context on the Bauhaus

The Bauhaus coincided with the timeline of the Weimar Republic from 1919 to 1933. The school's pre-history reaches back to the nineteenth century when the Industrial Revolution affected the labor conditions of the working class in general and skilled craftspeople in particular (Droste, 2006, p. 10).[43] Together with the changes in modes of manufacturing, the First World War marked a pivotal moment for the school's founders and students. The application of modern industrial production from mass commodities to mass destruction left a lasting impact on many. The Bauhaus, like other contemporaneous representatives of Western modernist design and architecture, was shaped by the

[42] My research on the Bauhaus covers only the Weimar and Dessau periods (1919 to 1931).
[43] On the prehistory of the Bauhaus, see also Klinger (2009).

contradictions that the War imposed on their ideals of the machine and technology.[44] Mindful of industry and technology's negative aspects, founding director Gropius thus pronounced that the Bauhaus's principal objective was to educate people as complete human beings. Like other European arts and crafts schools, it responded to this cultural crisis by reforming the predominant conservative arts and architecture education (Hahn, 2002). Drawing upon established intellectual approaches in reform pedagogy, as well as the antagonism between craft and industry, and the significance of the Industrial Revolution, Gropius coined the Bauhaus idea.[45]

Known as the 'new unity' of art and technology, the Bauhaus idea was the reformulation of the initial unity of art and craft after the first major overhaul of the institutional structure and curriculum in 1923. Gropius foresaw the school as bridging the conflicting sites of industry and craft. This underlying complexity, but also inconsistency, not only responded to the socio-economic conditions of the Weimar Republic, but it also shaped the Bauhaus's "dominant design framework" as anthropologist Keith Murphy asserts (2015, p. 54). For art historian Paul Greenhalgh (1990), this inaugural period of modern design and its representative collectives delivered a set of defining ideas in the form of manifestos and prototypes of how design could transform human consciousness and improve material conditions. First, the collectives strived for "decompartmentalization" by collapsing the boundaries between aesthetics, technology, and society. Second, design was assumed to possess the ability to improve social morality. Third, as the world had become chaotic, design and aesthetics were believed to be able to bring about order and progress. Going forth, it was believed that technology could serve the purposes above in both practical and symbolic ways. In order for this to be accomplished, the collective held that, "historical styles and [historical] technologies had to be eliminated wherever possible" (ibid., p. 11).[46] Halpern underlines in her history of post-war cybernetics and design practices of vision and reason that the Bauhaus "embraced the machine and technology and never taught history, as design should be taught according to principles, not precedent" (2014, p. 86).[47] That is to say, the Bauhaus informed design practice and profession as a 'science' in synthesis

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44 Notable examples include the Dutch De Stijl movement, Deutscher Werkbund, and Swiss-French architect Le Corbusier.

45 Similar ideas were already discussed at the Deutscher Werkbund, where Gropius was an active contributor prior to the Bauhaus. The Werkbund was a German association of craftspeople, industrials, architects, and artists created to support "a state-sponsored effort to integrate traditional crafts and industrial mass-production techniques." Retrieved from http://www.deutscher-werkbund.de/wir-im-dwb/basic-information-in-english/

46 Greenhalgh also identifies the inter-related aspects of truth, total work of art, function, abstraction, internationalism or universality, transformation of consciousness, and theology (ibid.).

47 Itten's late publication (1955) on his Bauhaus pedagogy, however, reveals that the school included at least in the preliminary course the study of "old masters" of art.

with technology and progress that is void of any lineage.

The Bauhaus Curriculum

Despite the broader perception as a stylistic movement, the Bauhaus was first and foremost an educational institution, making a curriculum indispensable. The Bauhaus curriculum consisted of two core components—the preliminary course and the workshop training (see Fig. 2.1). Initially open-structured, the curriculum led to students entering workshop practice unprepared in form theory. After this brief period of disorganization, the curriculum model, as shown in the circular diagram, became by and large the structure until the school's closure.[48]

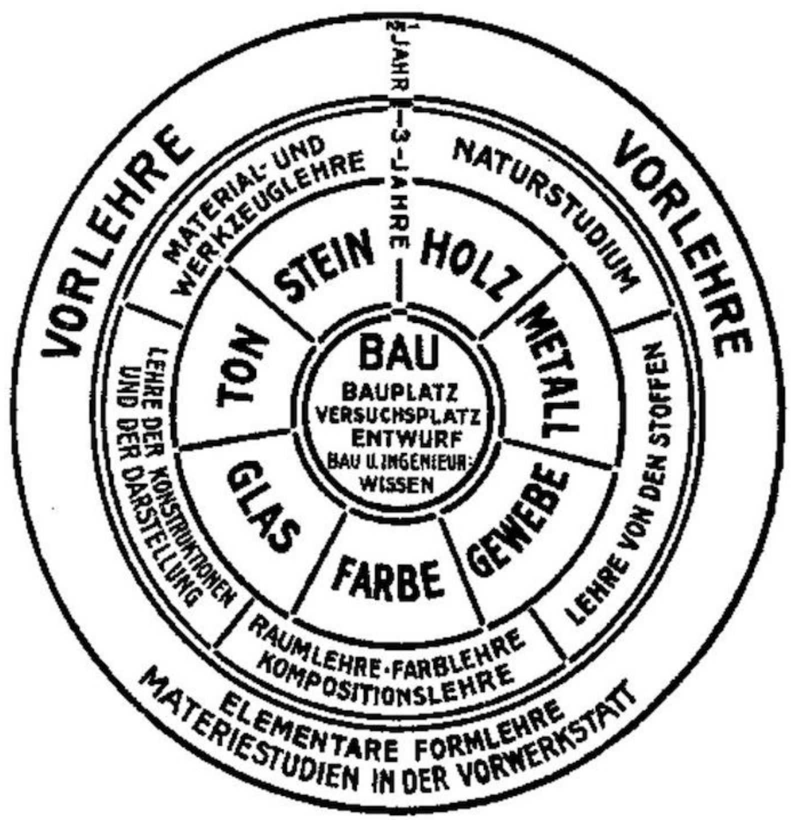

Fig. 2.1. The Bauhaus curriculum as of 1922.

The first school year (the diagram's outer circle) was dedicated to the preliminary course, upon which a student's talent was subjected. The preliminary course consisted of a somewhat traditional art

[48] With the approval of the masters' council, Itten's preliminary course and form studies became obligatory as of October 1920.

education based on the principles of experimentation and play, expanded by basic form and material studies in the preliminary workshop. Both aimed to prepare students for the successive workshop training (the diagram's inner two circles), making up the subsequent two to three years. The preliminary workshop training also let students discover their respective workshop area of preference. Most female students with a few exceptions, however, were restricted to the textile workshop. Lecture in material and color theory, tool theory, drafting, spatial construction, as well as sciences, supplemented the workshop practice. Upon completion of the workshop training, students passed an internal exam in their respective craft to become craft masters. As a final instance, the preliminary course and the workshop training would culminate in Gropius's envisioned building theory (the diagram's inner circle), that is architecture.[49]

The curriculum aspired to become a role model for the reformation of traditional art academies of the time while relying on not-so-novel ideas: the Arts-and-Crafts movement and the reform pedagogies of Jean-Jacques Rousseau, Heinrich Pestalozzi, and Friedrich Fröbel. They influenced Itten's inductive approach—learning by doing and experimentation instead of a paramount position of theory. Being the only form master with a pedagogical background, Itten took charge of the preliminary course. However, his educational model rejected an alignment to any specific goals, in particular, the pedagogic goal for Gropius and Itten's successor Moholy—a social relevance of aesthetic production. On top of that, the school struggled to provide the necessary infrastructure of workshops and materials to achieve this particular goal, which strengthened Itten's position among students. These two conditions presented the most significant challenge for the workshop curriculum as T'ai Smith (2014) remarks. After Itten's departure from the Bauhaus, the core curriculum structure remained unchanged except that it reoriented more clearly towards production. To achieve that, in 1923, the faculty introduced a type of intermediary shop floor work (Werkarbeit) hoping that it would connect better the preliminary course to the workshops and, thereby, encourage craft professionalization (Stoeber, 2009).

At the final instance, the workshops transformed from vocational shops to manufactories (Produktivwerkstätte) for the execution of commissioned works. This enterprise actualized with Moholy and Albers's takeover of the preliminary course and the prefatory 'shop floor work.' Between the two masters, Moholy primarily focused on the preliminary course, while Albers supervised the practical work. Moholy further changed the intention of the ancillary material studies. Based on a

[49] This goal remained unattainable until the respective architectural department was set up in 1927.

systematic analysis of material through kinaesthetic training, the students were prompted to study the material itself and less its sensual features. However, although Moholy's pedagogical approach was rationally-inclined, his position on the role of craft and the workshop training therein differed only subtly from Itten's one.[50] In his pedagogical reflections captured in his book *Von Material zur Architektur* (1929), he declared that the principal function of the Bauhaus workshop training was as an educational component, and not to become an end in itself.

The Promises of Partnering Up with Technology and Industry

A number of Bauhaus figures, especially Gropius and Moholy, were predisposed towards the idea that for arts and craft to survive amongst their mass-manufactured surrogates, the former should embrace the machine and the technological development of the particular period. However, the Bauhaus's primary focus was not on designing and producing highly mechanical or technical artifacts, rather on "improving industrial design" (Halpern, 2014, p. 86). The idea of aligning arts and craft with technology and industry through education preceded the founding of the Bauhaus. Already in 1916, Gropius expressed this vision in a memorandum to the Grand Ducal Ministry of State in Weimar, suggesting the establishment of an educational institution as an art consultancy for industry, economy, and craft. He called artists to actively engage with the means of industrial production in form-giving, "from the simplest tool to the complex specialized machine" (1916). The message to the 'future' artists was simple: collaborate with, instead of avoiding the machine or any other technical means for industrial production.[51]

This alliance with technology and thus with industry was not met with equal sympathy by other Bauhaus members, especially by preliminary course master Itten. Unlike his successors Albers and Moholy, who carried on his playful approach, Itten rejected the utilization of tools and technology in artistic practice for the sake of an industrial application. Itten, who supervised *all* workshops from 1921 on, demanded students either make individual artworks contrasting a consumption-oriented world or work with industry. Feeling threatened in many ways, Gropius had to reassure the Bauhäusler and the wider public that the school's principal plan remains to unite art, craft, and technology

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[50] For more on Moholy's kinaesthetic model of education, see chapter 5 of Zeynep Celik Alexander's book *Kinaesthetic Knowing: Aesthetics, Epistemology, Modern Design* (2017).

[51] While this position paper marks one of Gropius's earliest accounts of a school model that resembles the later established Bauhaus, it had a somewhat unsuccessful precedent two decades earlier as an earlier letter from van de Velde to Gropius revealed. This artistic institution as a consultancy for industry and crafts was rarely asked for advice. Instead, what grew out of it was the Kunstgewerbeschule, which later would merge with the Arts Academy to become the Bauhaus Weimar (van de Velde in Pennewitz, 2009).

regardless of Itten's or anybody else's predispositions. In a statement from February 3rd, 1922 about the differences of opinions between himself and Itten, distributed to the other form masters, he wrote,

> To come right out of it: I look for unity in the *fusion* of these forms of life, not in their *separation*. […] The Bauhaus has quite consciously aimed to replace the principle of the division of labour by returning to collaborative work in which the creative process is perceived to be an indivisible whole. […] The only basic contradiction is between the division of labour on the one hand, and collaborative effort, on the other—a synthetic conception rather than an analytic one. (1922, pp. 134-135; original emphasis)

Gropius was not alone in this opinion. In the book *Vision in Motion* (1947), Moholy reaffirms that "[t]he machine is understood as a very efficient "tool" which—if properly used—will serve the creative invention as well as the traditional hand tool" (p. 66).[52] The goal of lessening the fear of and the antipathy for the machine is restated over and over again in his writings, which resonates with the view of DIY and maker cultures on technology.

The Bauhaus Manifesto and the Role of Gropius's Communication Strategy

Manifestos seem perpetual: political parties and groups have them, artistic movements have them, and even technologists offer their versions.[53] Gropius launched the school in April 1919 with one as well. Frayling ascribes its publication to the fact that initially most Bauhaus masters "were artists rather than designers, so they were much stronger on writing manifestos about industry and producing wonderful visual aids […] than on practical results" (2011, p. 131). The Bauhaus Manifesto allowed Gropius to carve his vision of a unified art and design program that aims for the primacy of architecture. Besides that, it also emphasized a sense of progress. Manifestos present a way of breaking with the past, and Gropius and the Bauhaus were not far from this ideal. However, what exactly gave *this one* a revolutionary character? In the unstable period after the war and in search for supporters, that required an idea both commonplace and progressive. Gropius suggested in the Manifesto in the form of the unification of (fine) arts with craft acting as an ultimate source of creative design. It was forward-looking and rearward at the same time:

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[52] The book depicts different pedagogical exercises from "the educational technique" for the Institute of Design, the so-called New Bauhaus.

[53] The presence of manifestos is immense in the first half of the twentieth century with peak appearances after a global or local historical event. Notable examples mark the years 1908/1909 (publication of the Futurist Manifesto), 1918/1919 seeing the end of World War I, and 1967/1968 (protests of 1968 across the world). In more recent years, it shows a growing trend since the early 2000s.

> The art schools of old were incapable of producing this unity [that is the building]—and how could they, for art may not be taught. They must return to the workshop. This world of mere drawing and painting […] must at long last become a world that builds. (1919)

Just these few sentences allow for many interpretations. In a period of poverty and loss, an idealist existence of fine artists appeared as immoral and less worth supporting. Creativity had to serve the social goal of recovery and not of hedonism. By condemning the past practice of drawing and painting as unfulfilling such goals, it immediately creates an association of building and construction equal recovery and wealth. However, what more ordinary yet noble practice of building is there than craftsmanship and learning a trade? Herein, Gropius concealed his vision of architects or 'universal designers,' being taught in multiple artistic, theoretical, and craft practices as multifunctional professionals. That is to say that if an artist wanted to be an artist, they could maintain such existence. Whereas, if an artist trained in woodworking, metalworking, weaving, or another, wanted to apply these skills outside—in the industry, they would be best prepared for this new task. The key to such success, for Gropius, was instrumentalizing craft as the means of practice in a technology-supported, mass manufacturing economy, an idea that was inherently paradox as the Bauhaus history reveals. What made it appear as radical at the outset of the Bauhaus, however, was less this specific articulation by Gropius. Instead, it was his proclamation to level the hierarchy that existed between craft and art as I will illustrate in the next section.[54]

The Bauhaus: Themes for Social Design Practice

Leveling the Hierarchy between Craftspeople and Artists

Craft's place along art, design, and mass production has continuously been contested, moving somewhere dismissal and appraisal (Dormer, 1997; Risatti, 2007). In our information technologies-entrenched present, craft is regarded as a philosophy of practice applicable even to digital work like programming.[55] Recent developments such as the maker culture and digital fabrication celebrate craft

[54] Gropius revised the Manifesto a few times to adapt it to specific contexts. On the multiple revisions of the Manifesto, see Koehler, 2009. Her investigative essay on the history of the Bauhaus Manifesto argues that the revisionary practice of Gropius problematizes the Bauhaus and demands a more careful inspection.

[55] Sociologist Richard Sennett has popularized this idea in his book *The Craftsman* (2008), where he contends that programming, in particular, open-source and traditional crafts are not opposing each other. Instead, they form a continuity. He also states that in the United States earning a craft was commonly associated with a failure, that is failing to get a university degree. An empirical example of this association is Peter Korn's autobiographical reflection *Why We Make Things and why it Matters: The Education of a Craftman* (2017). Korn describes his path from getting a history degree at the University of Pennsylvania to becoming one of the best-known furniture makers in the US.

for its ingenuity of bridging distinct fields—in other words, a lateral vision of inventiveness. This vision captures the contemporary idea that "everyone is a maker," but also Bauhaus's vision of and, in particular, Gropius's strategic marketing of the class equivalence of art and craft. Craft in Weimar Germany had an uncertain place alongside industry. The country's economic situation demanded a faster and more cost-effective production mode than the one associated with craftsmanship. However, craft proposed a double advantage. First, as a counter to the low quality and 'lack of elegance' necessitated by mass manufacturing, it stood for centuries of mastery and skillful material manipulation.[56] Second, its regulation of craftspeople through degrees and market shares demeaned that it still exerted political power within the industrial landscape.[57] Gropius recognized these aspects as he knew that a newly established art school required becoming partners *with everyone*. The school's success depended on accepting craft and industrial production with craft being the intermediary between art and industrial production. That being so, the Bauhaus proclaimed a return to craft and workshop practice as a way of recreating industry. The establishing move, then, was to alleviate any hierarchies between craft and art formally. The idea's execution was to integrate craft in the Bauhaus curriculum.[58]

Gropius expressed the initial claim of leveling the hierarchies between artists and craftspeople in the Bauhaus Manifesto: "There is no essential difference between the artist and the artisan. The artist is an exalted artisan. […] So let us therefore create a new guild of craftsmen, free of the divisive class pretensions that endeavoured to raise a prideful barrier between craftsmen and artists!" (1919). What sounded like a model of societal transformation for the current industrial production was meant to happen only within the Bauhaus confines. It was a generative attempt for a symbiosis of art, craft, and industry. For Gropius, the 'old craftsmanship' and the precursory model of the production chain, that is the craftsperson combining the different work of technician, salesperson, and artist in the same person, represented this symbiosis. The reality at the Bauhaus, however, was quite different from Gropius's vision in the Manifesto. The model of collaboration and unity, which should serve as a

[56] Gropius elaborated the idea of refining industrial, machine-made products through art wrote in a 1913 essay presented at the Werkbund. He emphasized that a replacement of handwork by the machine could be brought to completion only if industry pays equal attention to the removal of flaws in surrogate products, to refine them with the "noble features of handicraft products along the advantages of machine production," and to coping with artistic matters (ibid.).
[57] Craft in Germany was heavily regulated and organized in the Chamber of Crafts, which developed out of the medieval guilds. The guilds regulated developments of the class organization in society.
[58] As the Bauhaus's education model got replicated in many other design and art schools after its closure, craft once again lost its status. British arts and design writer Peter Dormer notes that by the end of the 1960s craftsmanship nearly disappeared from the curriculum and was devalued (1997). Interestingly, Dormer traces the point of departure in the preliminary course at the Bauhaus model. He argues that, although the introduction of craft at the Bauhaus is well recognized, it played a minor role in design history.

prototype for the industry, failed to be carried out at first. A separation between craftspeople and artists maintained even within the school.

The position of craftspeople amongst the Bauhaus teachers was secondary as the few existing documents on their work and practices suggest. Besides, they barely achieved the masterly popularity of their artistic colleagues amongst students. With an initial mandate to link the existing Weimar Academy of Fine Arts with the Grand Ducal School of Arts and Crafts, the Bauhaus had to keep the old schools' faculty besides new hires. Many of the old faculty members saw themselves threatened by Gropius's attempt to level the difference between art and craft. It was a question of nobility and thus of power as art historian Elaine S. Hochman indicates (1997, p. 84). However, the idea of leveling hierarchies did not resonate quite well with some of the new hires either, in particular, with Itten. As described earlier, his approach to craft was not instrumental as Gropius's, he understood it as part of his arts pedagogy for *l'art pour l'art*. The artistic faculty also saw themselves endangered by the deliberate use of the term *vocation* for the masters of craft in the school's statutes.[59] However, the short moment of equality was revoked in 1921 with a binding decision on the distribution of responsibilities. From that moment on every workshop was the subject of supervision by a master of form, who would guide the craft pedagogy according to the principles of design (Schüler, 2013). The masters of craft were downgraded to technical supervisors of the workshops.[60]

Finding suitable craftspeople according to Gropius's requirements proved difficult. First, he demanded that a craftsperson had an artistic background or some artistic training. Second, the candidate should be susceptible to the Bauhaus idea or otherwise participate in the artistic program if necessary. Moreover, they should be in possession of a 'Meisterbrief,' i.e., a master craftsperson diploma, or have the examination in prospect (ibid., 9). This list of requirements suggests that they were tailored for the future Bauhaus-educated students to turn their talent, skills, and knowledge into educational practice there or elsewhere. Indeed, with the relocation to Dessau masters of craft gained a better standing by uniting them with the masters of form within one person. It was the first generation of Bauhaus graduates inaugurating Gropius's new guild, who would lead some of its most famous workshops: Josef Albers (glass), Marianne Brandt (metal), Marcel Breuer (cabinetmaking), and Gunta Stölzl (weaving) (ibid, p. 19).

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[59] This term applies typically to academic staff as the artistic master of form notes Schüler (2013, p. 8). He points out that such linguistic phrasing suggests a revaluation of the master of craft as equivalent partners to the artists in the education (ibid.).

[60] The masters of craft also did not receive equal pay as their artistic colleagues.

The Meaning of Specialization

Specialization primarily is "the process of concentrating on and becoming expert in a particular subject or skill."[61] Achieving specialization requires a demarcation to other work processes and practices, often by their division. However, these two inter-related concepts, specialization, and division of labor hold a level of contradiction. On the one side, in the broader history of industrialization and its impact, the concept of division of labor emphasizes increased deskilling of labor and reduction of expertise and creativity (Braverman, 1974).[62] On the other, the critique of the division of labor highlights a leap of over-specialization concerning single-task skills within an individual, which deskills with regards to other related skills and the diminution of creative thinking. The Bauhaus's position on specialization was one of disapproval. On the surface, Gropius, together Moholy and Albers, argued against specialization in work. They promoted a view of equality and totality in terms of creative abilities. Their idea of rejecting specialization in work processes and any practice coupled to the recognition of pervasiveness of creativity which resonated with the promise of leveling hierarchies. Altogether, it let the Bauhaus appear as inclusionary and empowering the workforce towards a future democratic society. However, their positions on specialization and on 'everyone being creative' unfolded in different directions.

Some of Gropius's earliest Bauhaus writings took up the idea against specialization and for totality as their central topic.[63] Gropius blamed the same technological developments—the assembly line and industrial production—he sought to partner up and improve their creations through artistic influence for having generated a specialized workforce reduced of creativity (1922, p.1). Gropius's writing, however, is known for shifting perspectives in response to different audiences and needs (Franciscono, 1971). He employed the machine and technology somewhat contextually. Likewise, Moholy repudiated specialization in work and professions and the loss of a multiplicity of vocations resulting from the introduction of industrial machine production. In his 1966 essay "Erziehung für eine technische Welt" (Education for a Technical World), he commented that the problem was the response of the educational system. For Moholy, education was a product of the contemporary modes of manufacturing; it compelled individuals to consider only one specific profession, thus turning them

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61 Definition "Specialization," Oxford Dictionary of English.

62 On a critique of revision of Braverman's reading of Marx, see the edited collection by Stephen Wood (1982); also MacKenzie & Wajcman (1985).

63 For instance, in the draft of his 1922 speech, "*Einheit von Kunst, Technik und Wirtschaft eine Gegenwartsutopie?*" (Unity of Art, Technology and Economy a Contemporary Utopia?), he maintained that totality is necessitated by specialization. His later essay "Bauhausindustrie" (1923) reveals a more disapproving tone against specialization of the individual precipitated by industry and economy.

into experts (ibid., p. 14).[64] He offers a similar analysis of the contemporary situation in his famous post-mortem published book *Vision in Motion* (1947), looking at topics such as specialists, classifications of education, the relationship of art and science, as well as the place of the amateur. Specialization, again, is ascribed to "the wheels of industry" (ibid, p. 15). Industry deprived the craftsperson of "[a]ll former responsibilities and pride […] in the wholeness of a product[,]" forcing them to work "in the maze of tunnels and gangways of the specialized labyrinths" (pp. 15-16). Hence, the educational system "attained a vocational aspect[,]" losing for Moholy their highest quality, that is universality, and the "sense of synthesis to the extent of a complete separation of the various types of experience" (ibid.)

However, Moholy also applied the term 'specialist' interchangeably. Whereas industry and the attached vocational education produced a form of second-rate specialists, he recalled the Bauhaus as having to create a superior group of specialists, that is the "designer-specialist." As sociologists and historians of work have discussed, professions, specialization, and education are deeply intertwined (Abbott, 1988; Sarfatti Larson, 1977). Each Bauhaus student was allowed to enter a specific workshop "for professional training" after passing the first year of the preliminary course. According to Moholy, "[t]he main principle of such specialized work is the study of design in theory and practice; industrial processes and materials, and the mechanics of a functional and creative approach" (ibid., p. 86). The difference to the division of labor determined by industrial production here is that, "the student has to know infinitely more than a single a workshop can give; he must work in various materials and besides his special problems he must reach out to other design tasks, for which systematic investigations constantly are carried out in the different workshops" (ibid.). Moholy's description of the Bauhaus workshop training thus frames design as descending from the conventional craft approach, which encompasses all procedural steps within one person but allowing for a specialization in the respective workshop domain of practice.

Both Moholy and Albers actively engaged in the teaching of the preliminary course and in the workshop practice, which strongly influenced their design pedagogy. They believed that everyone had creative potential and eventually could be involved in a creative process. Moholy expressed that although every individual is talented and creative, the form-giving through the material is tantamount to art (1966, p. 17). Unlike Moholy, Albers was much more generous in terms of ascribing creativity.

[64] Moholy referred to the specialized individual as "sectorial man." The multiple one he called "central, collective, organically growing." However, Moholy like Gropius did not blame technology for causing this development. Moholy's stance was quite deterministic arguing that "technology is an organic, self-developing constituent of life, which interacts in correlation to the growth of humanity" (ibid., p. 15). He called this technology's organic right.

In "Simply on Education" (1934), he notes that the tendency to divide between qualified and unqualified, or original and copy, is inapposite. Instead, the ambition should be to "increase or expand the better group," not by separation, but by inclusion (ibid.).[65] However, their perceptions of everyone being creative did not translate into everyone having equal opportunities and access to creative work at the Bauhaus. Initially open to enrolment, the Bauhaus changed this practice with an entrance examination for the assessment of artistic talent. Students also paid tuition with funding opportunities being limited, and only an insignificant number of students succeeded in earning royalties from their student craftwork.[66] Besides that, at the time being a craftsperson meant being a specialized professional. Traditionally, this work combined a variety of skills: the recognition of market needs, the translation of customer requests into ideas and products, and the operation with the typical for the craft tools and machines. While this might respond to an idea of unity and against specialization, the reality at the Bauhaus represented a sharp division between the different workshops, encouraging students to choose only one area of work. Thus they ended up mastering that one only as specialists.

Workshops as Laboratories for Serial Production

The workshops had a problematic start. In the Weimar phase, where the school was housed in the building of the old school of arts and crafts, the Bauhaus could not provide all of the envisioned workshops.[67] For some of them, it sought access to external ones. Others such as the metal and weaving workshop lacked access to the specific machines.[68] In an essay written prior to the school's foundation, Gropius's model for the initial setup of workshops suggested that parents and local craftspeople should contribute the proper tools for the school to function (1918). His idea resonates

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[65] With a few exceptions from his time at the Bauhaus, most of Albers's writings on art and education were published after he and Anni relocated to the Black Mountain College.

[66] The two most successful workshops in achieving the proclaimed unity and of educating the 'future workers' for developing prototypes for serial production were the metal and weaving ones. Students such as Marianne Brandt with her famous Kandem lamps or Gunta Stölzl with her carpets managed to develop objects combining modern design, mass-manufacturing, and an experimental attitude.

[67] The Bauhaus scholarship has grouped the school's lifetime in different periods. Besides a standard classification of the institution in the years of the respectively designated director, others have ordered the periods according to the original artistic styles or developmental aspect. Christian Grohn (1991) divides the periods into the 'expressionist phase' from 1919 to 1922, the 'formalist phase' from 1922 to 1925, the 'functionalist phase' from 1925 to 1927, and the remainder as the Hannes Meyer phase from 1927 to 1930 and the Ludwig Mies van der Rohe phase from 1930 to its end. According to design historian Bernhard Bürdek (2005), the school's lifespan can be classified into the 'foundation phase' from 1919 to 1923, the 'consolidation phase' from 1923 to 1928, and finally the 'disintegration phase' from 1928 to 1933.

[68] The metal workshop had to contrive until 1923 only with the tools and machines of the silversmith. Similar limitations were found in the weaving workshop, hand weaving made most of the early projects. Even others such as the cabinetmaking workshop, though central at the Bauhaus, were difficult to be established due to the nonexistence of a prior equivalent in the building, and later it lacked a budget to acquire "more substantial machines," leaving students to accomplish projects with simple lathes and basic woodworking tools.

with the way contemporary member-run makerspaces acquire technical equipment by donation.

However, the workshop education also suffered the problem of adequate supervision. While some of the pre-existing workshops such as bookbinding or ceramics could take over some the craftspeople, other workshops had difficulties appointing a supervising craftsperson.[69] The question of power represented in the supervision of workshops shaped its first years. Otto Dorfner, master of the Weimar bookbinding workshop, recommended that the school should focus on the workshops, "which he wanted upgraded and made capable of producing prototype models for industry, a so-called Bauhaus collection" (quoted in Hochman, 1997, p. 136). As a head of a workshop, he proposed two significant changes: first, hiring an experienced corporate counsel (Syndikus) to develop a business model of operation; second, that masters of craft are accepted in the master's council and receive a vote on related matters. Assigning the primary responsibility for all workshop matters to the form masters was also met with reservation by some of the students. They were somewhat inclined to accept the two distinct masters in equal terms for their respective set of skills and knowledge.[70] Finally, the year 1923 also marked another significant shift for the workshops as Gropius's narrative moved away from the medieval 'Bauhütte' with its unity of art and craft to the timely 'new unity of art and technology.'

The Bauhaus was shaped and reshaped in multiple ways. From the "Staatliches Bauhaus" Weimar it became after relocating to Dessau the first school in design—"Bauhaus – Hochschule für Gestaltung." Dessau, a prospective industry center, offered a benevolent location for the school in political, economic and social terms. Open-minded supporters such as local aircraft engineer and designer Hugo Junkers, a socialist and pacifist, worked in close cooperation with the school.[71] The political closure of the Weimar location and the school's public repudiation fostered, even more, the consolidation of the vision of design for industrial production in Dessau. It affected Gropius's narrative on the Bauhaus as a site for production. The workshops transfigured from laboratories for prototypes for serial production to laboratories for a new type of workers for industry and craft without any precedence (Gropius, 1925). Craft in his depiction was modernized to become "a test bed

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[69] On the requirements set by Gropius, see the section "Leveling the Hierarchy between Craftspeople and Artists."

[70] As Marianne Brandt ([1971] 1985) reminisced about different aspects of the Bauhaus and the workshop practice, the workshops epitomized a pendulum between the form and craft, but more than often being a hybrid between them. As she recalled, "We always had a master of craft on our side in our [metal] workshop and we got on well with this division—here design [form-giving], there craft. Though it was necessary to change multiple times [between them]." (my translation, ibid., p. 159). Brand't account demonstrates how the hierarchy between artists and craftspeople was perceived as something unavoidable.

[71] Junkers collaborated with the Bauhaus in different areas: from industrial furniture to social housing for the growing local population.

for industrial production" (ibid., p. 135 [8]). Going even a step further, he labeled this innovative craft practice as "speculative experiments of laboratory workshops for the creation of models – types – for [their] productive execution in factories" (ibid.). While Gropius was narrating this vision, its accomplishment had to be outsourced like some of the actual manufacturing, for instance, of Breuer's famous steel armchair at Junkers aircraft factory. The school's dependency on external funding by the government and the local industry enforced his narrative strategy.

The rendition of workshops for prototypes for mass-production lines up with "rationalist design concepts tending to serve the economy," as Forgács describes (2016, p. 62). Besides, these interpretations of the workshops' function illustrate that, at least for some of the Bauhäusler, the school's essence was in partaking in, what historian of technology Leo Marx calls, "the abstract, intangible, neutral, and fittingly synthetic idea of technology" (2010, p. 574). However, while Marx describes technology practice as having detached entirely from the mechanic arts, which "[call] to mind men with soiled hands tinkering at workbenches […] [and] belong to the mundane world of work, physicality, and practicality—of humdrum handicrafts and artisanal skills" (ibid.), the Bauhaus could only achieve it with the means of the mechanic arts. However, as Lou Scheper, an active member of the stage workshop and leading figure in the field of colour design in Berlin's post-war architectural landscape, emphasized, the "norms for industrially manufactured items for everyday use" at the Bauhaus resided in the handcrafted individual piece ([1971] 1985, p. 176). The majority of its workshop areas, but especially the metal and weaving ones, being the most successful regarding technical aptness, had difficulties meeting the actual mass manufacturing standards of the period.

The metal workshop began its work in 1920. Initially, its equipment consisted of the tools and machines of the silversmith only, but it also suffered restrictions concerning space and staff. The majority of objects produced at the beginning were household containers based on simple geometrical forms, that is circles, spheres, or cylinders. A possible explanation for the disposition towards these simple geometries, as Droste (2006, p. 78) proposes, was a lack of knowledge of manufacturing processes, and the belief that simple forms are particularly easy to be produced industrially. With Moholy's takeover of the supervision after Itten's leave, the workshop reoriented its goal towards mass-manufacturable prototypes. Moholy introduced diverse materials and promoted the experimental work on a distinct to the silversmith's practice object, namely the lamp—"epitome of the school's design program" (Karate, 2006, p. 166). Still, the execution remained entirely manual (ibid., p. 78). Besides most objects were produced in teamwork as the manual process was slow and laborious for a single person. Thus, the technological limitations prevented the lamps from being produced in large quantities, making them too expensive for the broader market.

The textile workshop, better known as the weaving workshop, was an exception regarding the fulfillment of the Bauhaus objective of serial prototypes.[72] Being one of the most developed industries of the time, weaving as a technical process was an ideal prerequisite for this goal (Droste, 2006, p. 72). Its proposed curriculum entailed a list of skills that read like a handbook of factory management. However, students lacked knowledge and skills of weaving techniques. Craft master Helene Börner could not instruct adequately and her teaching was not systematic (Elste, 2006; T. Smith, 2014). The initial absence of industrial looms set other limitations. Some of the proposed skills in the curriculum, for instance, dyeing and factory management, were not offered at all and needed to be acquired outside of the school.[73] Thus, the initial designs produced were of little use for an industrial reproduction. Only with the relocation to Dessau, the weaving workshop became fully immersed in the "functionalist paradigm." Supervising form master Georg Muche, together with student Gunta Stölzl, who took over the craft training in weaving, equipped it with jacquard looms and loom systems for training equivalent to the manufacturing standards. As a result, the workshop intensified its structural capacities towards a functional production business ("Produktivbetrieb"). Additionally, the process of weaving design became systematic by teaching the full production line from dying through weaving up to the manufacturing of the fabric. To meet the demands and standards of the industry appropriately, students started taking internships in textile businesses to reiterate the acquired skills into their workshop practice and education.

These two Bauhaus workshops provide a depth of analytical perspectives for the relation to the respective manufacturing sectors and their technologies which exceeds the scope and subject of this chapter. However, they also correspond with the idea of contemporary digital fabrication technologies and spaces as sites for industrial prototyping. Using insights from these historical precedents as my point of analytical reference, in the next section I want to illustrate how the Bauhaus idea and its actualization becomes epitomized in the representation of contemporary and historical craft and DIY in a recent exhibition at the Bauhaus museum in Dessau, in the participation of (design) students in makerspace activities, as well as in two contemporary maker-developed "prototypes for serial production."

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72 The weaving workshop was initially labeled as the *textile workshop* as the curriculum involved a range of techniques besides weaving.

73 Indeed, Gunta Stölzl and Benita Koch-Otte attended related courses at the Dyeing Technical School and the Textile Technical School in Krefeld.

Digital Fabrication: A "Bauhaus" of the Present

On Situating Digital Fabrication in the Bauhaus: A Vignette

The functions of the Bauhaus workshops and their momentousness were the focus of a recent exhibition titled "Craft Becomes Modern. The Bauhaus in the Making," housed in the former workshop wing of the original Dessau school building.[74] Aiming to locate the place of craft and the workshops, "[i]n the microcosm of workshop practice," according to its curators, "the exhibition shows the prevailing wide-ranging field of conflict in which craft at the Bauhaus was redefined as a utopia, albeit one that coexisted with industrial culture" (2017). While their objective recounts part of this chapter's subject, what connects the exhibition's focus to my inquiry on digital fabrication and maker practices within design is its juxtaposition of historical and contemporary positions in design. To that end, the exhibition dedicated an entire space to contemporary design projects influenced by craft, digital fabrication technologies, and maker practices.[75]

In summer 2017, I visited the exhibition to see and understand how these seemingly unconnected pasts and presents speak to each other. The exhibition's answer was in the translation of the idea of craft. The visitor was guided to discover the Bauhaus 'utopia of craft' by beginning with the actual presence of DIY approaches, craft practices, and digital fabrication technologies as they become implemented in design practice. In a small, studio-sized room, one saw and read the positions of the included current designers through displays of visuals, sketches, videos of their work practice, materials, and, finally, the designed objects themselves. In the back of the room, on a large meeting table and a shelf, the visitor could learn about objects manufactured by local primary school students as part of workshops supplementing the exhibition program. These objects served to demonstrate essential aspects connected to DIY, participatory design practice: collaboration, experimentation, drawing, prototyping, making, materiality.

I was not allowed to take any photographs of the exhibited works, recent or historical, so I scribbled down some notes to supplement them later with descriptions from the official exhibition catalog. I tried to capture the exhibition as a narrated story, but I failed. Everything I had learned about the Bauhaus, digital fabrication, craft, and DIY so far, obscured my immediate perspective. In

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[74] The English translation of the exhibition's subtitle reads like a process description. It suggests a picture of the school's unfolding over its short lifespan. Meanwhile, the German subtitle "Vom Herstellen am Bauhaus" is translated as "Of Manufacturing/Making at the Bauhaus." Unlike the English subtitle, it offers a clear description of the context of the exhibition.

[75] The showcase included the design work of, for instance, French-Moroccan designer Sara Ouhaddou, Italian design studio Formafantasma, Dutch designer Dirk Vander Kooij, or the online platform Opendesk.

hindsight, it meant that I misinterpreted the curators' intention of a thematic order of representation of (design) development. I realized that this reverse strategy of the exhibition display worked to make the visitor better frame how craft practice implements itself towards the Bauhaus idea of design for mass production. As the curators describe in the exhibition booklet, "[the exhibited works] demonstrate with experimental, activism-orientated, socially engaged projects aligned with vernacular tradition that craft today is a hybrid sphere in which the boundaries between design and manufacture, expert and amateur are dissolving and in which thinking and doing are being reconnected" (2017, p. 5).

From the present-day portion of the exhibit, one was directed to the historical part, which was located within the historic Bauhaus weaving workshop. The room comprised an entire wing of the floor divided into four subsections. First, using examples from the historical wood, weaving, and metal workshops, it looked at the tension between masters of craft and masters of form. Second, displaying machines and tools (apparently for the first time in a Bauhaus-related exhibition), it highlighted technologies and methods of shaping and working with the material. Third, "material lessons" demonstrated how materials became integrated into teaching. Finally, by writing "object biographies," the fourth subsection followed the trajectory from idea to everyday object in the case of a few commercially successful Bauhaus designs. Here, according to the exhibition's leitmotif, the visitor is offered the reconstruction of "craft at the Bauhaus as utopia" (ibid., p. 4) by "finding creative ways forward in a social setting in which the distance between everyday things and their manufacturers and users had grown" (ibid.). The exhibition further perpetuates that "[a] similar situation appears to prevail today: Embroidery, do-it-yourself and the digital crafts have ceased to be contradictory and now offer scenarios for human initiative in a world shaped by digitalization, globalization and technology" (ibid.). Corresponding motivations reappear in different maker narratives where the democratization of manufacturing technologies and processes is considered supportive for the maker cultures' claims of providing solutions to this issue. Similarly, both exhibition and maker cultures retain a reasonably unquestioned position on how the contemporary developments of DIY, making, and digital fabrication are being shaped by and connected to industry, commerce, and educational institutions as I aim to show in the following two empirical accounts.

Makerspaces as Workshops for Students

> *And then we have all the part-time members or the evening members who are mainly students […]. [I]t's everything from architectural students to technical students to carpenters.*
> (M. Christensen, personal communication, February 15, 2017)
>
> —Underbroen, Copenhagen, 2017

If you look around a makerspace, you will find many young members, often working in small groups. Higher education (HE) students make up a sizeable number of the users and members of makerspaces for some reasons. Similar to the role of the workshops at the Bauhaus, students broadly engage in makerspaces for developing skills and habits of hands-on production or in design terms, "material product development." However, also for more effortless access to standard industrial technologies which reminds of the difficulties that the Bauhaus weaving workshop had in keeping up with actual industrial standards, although, the development of this industry predisposed the opposite. For instance, in Berlin, I met fashion design students who were using the Textile Lab area of the Fab Lab Berlin to get access to electronic fabrication technologies. At the same time, some of them were co-shaping the infrastructure of the textile lab with self-organized activities or the contribution of textile technology (see Fig. 2.2).[76] At the Arduino office in Turin with its adjoined fab lab, local Politecnico students were prototyping a project with their help. However, students from various institutions got also involved in the initial stage of the Arduino's Casa Jasmina Internet of Things house project.[77]

The interest in students but also in the emerging alliances between makerspaces, HE institutions, and industry have also become the objective of several EU-funded research projects such as the Open Design & Manufacturing Project (OD&M).[78] This study emphasizes that at least three types of educational and professionalization initiatives can be identified: first, offering compulsory or optional courses on open design and manufacturing within art, design, architecture, and engineering

[76] The connection between textile and electronics has been elaborated in different areas of research (see Nakamura, 2014; Pérez-Bustos, 2017; Rosner, 2018). Interestingly, Anni Albers articulated early on how computing might interact with textile. Reflecting on her experience in her book *On Weaving* (1965), she notes that mechanical weaving restricted the creative flexibility and patterns. The shortcoming of traditional weaving and looms for Albers could be overcome with "new systems of flexible manufacturing, […], especially with textile production merging into computing" (T. Smith, 2014, p. 165). Computation, indeed, would become the manufacturing standard in textile production.

[77] These included amongst many the local Politecnico di Torin, the Politecnico di Milano, as well as the Royal College of Arts London as Casa Jasmina project manager Alessandro Squatrito tells me (2016).

[78] OD&M is the abbreviation for "A Knowledge Alliance between Higher Education Institutions, Makers and Manufacturers to boost Open Design & Manufacturing in Europe," a joint research project between the University of Florence, the University of Deusto, the University of the Arts London, the University of Dąbrowa Górnicza, the P2P Foundation, and the Furniture and Furnishing Centre. It commenced on January 1st, 2017, and runs for three years.

departments; second, participating in "[s]tructured projects of research and experimental extracurricular activities, often combined with innovative students' internships within companies […] or focused on complementary learning approaches" (Lobascio, 2017, p. 31); and, third, establishing institutional makerspaces and workshops (see Fig. 2.3). As such, these activities are initiated and directed by the HE institutions. One of the most articulate examples of this reciprocal relationship is the Institute for Advanced Architecture of Catalonia, host of the Fab Lab Barcelona and a leading site of the Fab Lab network. In this section, then, I want to elaborate on the specific user group of HE students as discovered across the sites of my study. The careful composition of these examples allows expanding the different modes and reasons for students' engagement in this form of practice beyond the suggested institutional initiatives articulated in the OD&M report. While some of the examples concur with the categorization of the OD&M report, they offer a more subtle interpretation of the complexity of the relationships between individuals, institutions, technologies, and practices.

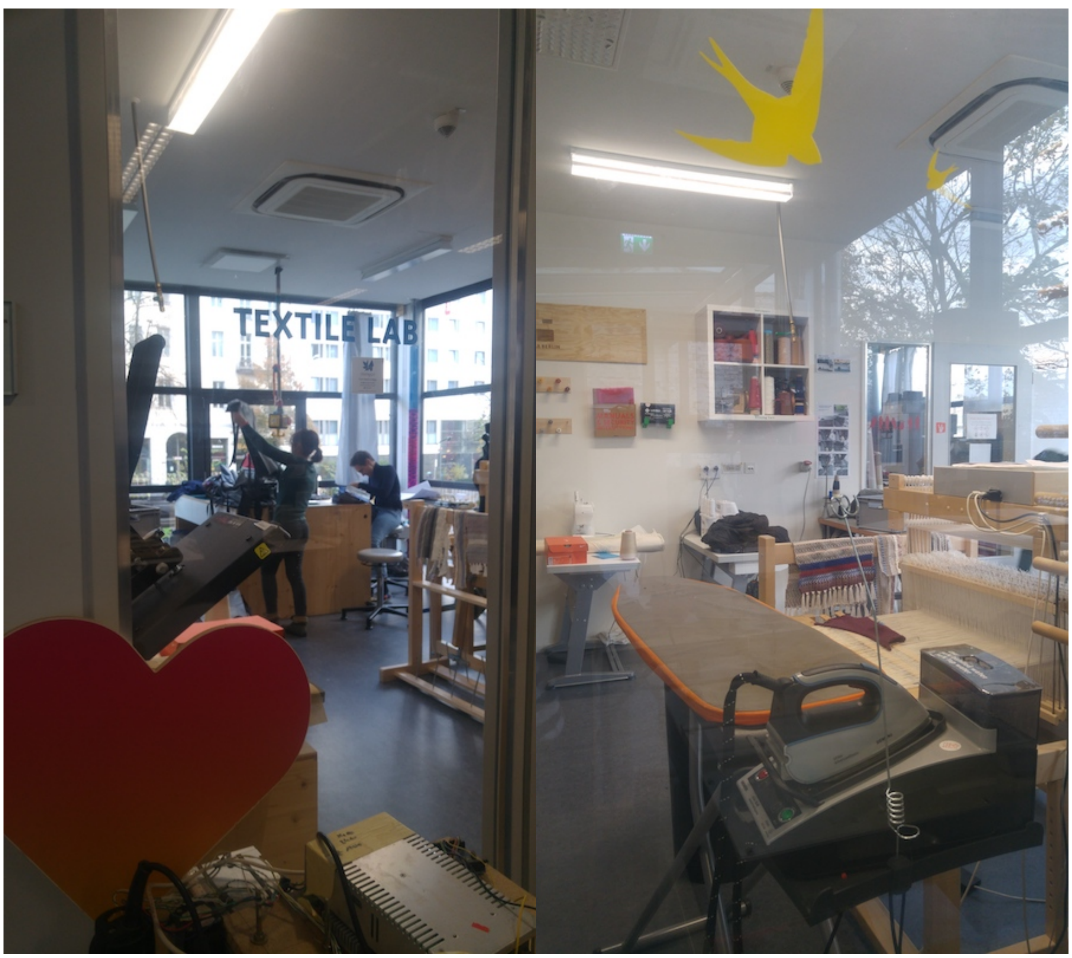

Fig. 2.2. Textile Lab at Fab Lab Berlin.

Fig. 2.3. The institutional “makerspace” at FHNW, Basel.

Limited access to machines and workshops at HE institutions mostly determines why HE students use makerspaces and engage in practices of making. Restrictions range from constraining workshop opening times to regular institution business hours, in particular, because these places are typically supervised by in-house technicians, over limiting use time for each student or team due to the high number of projects executed within the facilities, to limiting machine use to university-related projects only. These restrictitions might be considered as diminishing students’ ability to unfold their creative practice through personal or external projects. Such constraints brought one of Happylab Vienna’s fab lab managers as a student to the space. His access to the university workshops was restricted. He even describes the situation at the local universities as convoluted:

> *Each institute [i.e., faculty or department] has their machines and their workshop. If you are affiliated with one institute, you cannot use the machines from another workshop or institute. That is incredibly complicated. Then there are even stricter rules. For example, I did my thesis work at the Atominstitut in Vienna. They have a workshop, and as a graduating student, I was not allowed to use the drill press on my own.* (R. Jung, personal communication, May 12, 2016)

In contrast, Happylab’s setup was beneficial for his thesis work as it helped overcome the confusing, long-established university regulations. For others, these infrastructural limitations mean that they get little opportunity to practice and to improve hands-on making skills beyond their academic assignments as he comments. His example devises a typical problem that architectural students encounter in higher education. He explains that, for instance, the local institutional workshop for architectural model making owns two laser cutters. What seems like a lot as most makerspaces often have only one, sometimes two machines, however, might not be enough, when the access is limited to a nine-to-five workday.

This scenario recalls the objective and interest in laser cutting of an upper-year architectural student whom I met during a fab lab tour in Munich. She had to create her models with a laser cutter, but first had to learn how to use the machine. The fab lab employee asked her about the situation at her university and whether they had machines. She gave us an affirmative answer to her institution's machine availability, but then noted that the institutional laser cutters are overbooked and there is little chance she would be able to finish her term assignments there on time. The Bauhaus workshops, for example, suffered a similar problem of overcrowding which became partially solved by imposing specific regulations. An objectionable case includes the establishment of the weaving workshop not necessarily to increase the diversity of design practice, but to ensure that the growing number of female students is not taking up the more "masculine" workshops as Gropius discerned the situation.[79]

The rationale for machine use in institutional workshops is formally defined, as Happylab's repeats: "there is strict control over what is done with it. They [students] are only allowed to make university projects. [...] Nothing personal." (Jung, 2016). Nonetheless, laser cutters along with additive manufacturing and robotics are becoming the standard in architectural fabrication as dedicated events such as Fabricate, a triennial international conference on digital fabrication, indicate.[80] Especially for the process of planning and model making, laser cutting ensures an immediate and precise translation of CAD plans without an intervention of an 'imprecise' human hand. The implementation of CAD and CAM, which improves the pace of plan drafting on the one side, and makes the human labor of drafters and modelers obsolete, on the other (see Henderson, 1998), calls for a restrictive delegation of the human agency to mere assembling. This step, however, is also demanding in its achievement despite what recent developments in construction and architecture (parametric design, building information modeling, large-format 3D printing) tend to advocate. That is to say that although model making workshops and the newer technological advancements become integrated into the architectural curriculum (also in design and engineering), these CAD/CAM practices require

[79] The issue of overcrowdedness became smaller as its enrollment numbers declined over the years.
[80] On the most recent Fabricate conference from the eponymous series, see the website http://www.fabricate2017.org/conference/.

extracurricular activities for their mastery. Compared to a dedicated professional apprenticeship or training with a substantial number of hours for learning and practicing, architectural schools tend to underestimate the time required for practice. As a result, it leads to HE students having to look for external opportunities to acquire the technical proficiency in CAD/CAM.

Personal projects, for instance, enable this type training as well as act as professionalization. Niki's internship at Machines Room in London makes a point for that. The team introduced Niki as their Erasmus exchange program intern.[81] She had graduated from architectural school three years earlier and since then had "decided to attend another master program near [her] hometown, which is about furniture and wooden structure[s]" (N. Nefeli, personal communication, January 16, 2018). Her interest in CNC milling and additive manufacturing but also making things by hand, motivated her to come to Machines Room. Instead of doing an internship at an architectural office as expected, she picked this makerspace based on a friend's recommendation that it could allow her to do all these things, as she describes:

> So your Master degree is related to furniture design and joinery?
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> *Well, actually, yeah, it did. It was a technical university in a small town, near my town. And the master program, yeah, I was not satisfied about that, because it was more like sitting and watching presentations and stuff. So, here I'm practicing those methods that I just heard of or saw in a presentation.*
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> And you didn't have any physical workshop in your school, where you can actually work with a laser cutter or a CNC to make stuff?
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> *There were those kinds of tools, but I don't know why the master program, they tend to keep it in theory. They don't allow you to just mess that much with tools. So I wanted to do that, and this is the way that I can take all of the knowledge in practice and then go back and finish my final project for the master program.*
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> Does that mean that you did not learn CNC or laser cutting before you came here?
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> *We learned the software but never actually [manufactured with] it. We used 3D printing but not the CNC. It was not used during the program.*
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> What kind of software and which processes did you learn in university?
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> *Well, architectural [software] and a lot of stuff. First of all, AutoCAD and Photoshop, and all the Adobe stuff. And then it was up to us if we wanted to get involved with 3D programs like Rhino or AutoCAD or that kind of stuff. So, it was ... We did it by ourselves. No one taught us that.*

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[81] The Erasmus Programme is the standard label for a range of EU-funding activities aimed at supporting education and youth training with a particular focus on an international exchange between post-secondary institutions.

What about the CAD/CAM software pipeline? Where you also learning the entire programming to work with the machine?

It's a CAD/CAM program [she was trying to remember the name of a specific CAD/CAM software application]. But we learn how to design a product in that software so that we can show it or present it. We didn't learn how to use the CNC in the same [way] related to the program. But for the 3D printing, it was actually pretty easy because you just design something, and you just use the slicing program and that's it.

She mentioned that technical manipulation with laser cutters, 3D printers, and the specific CAD software was part of the postgraduate degree in architecture but not of her undergraduate. In a way, this also depends on the period when a student started their studies in architecture or one of the disciplines mentioned above as the broader adoption of digital fabrication and rapid prototyping technologies by HE institutions has only incrementally happened over the past two decades. Also, the introduction of digital fabrication into a curriculum is contingent upon the geography of the institution. Niki studies in a smaller provincial town in Greece. She recognizes this as an impediment for young people to stay in the region and to be able to practice and contribute to the local social life and community. Her experience is not unique, though; nor are the economic conditions of Europe's south entirely determining the provision of digital fabrication technologies as the educational background of another Machines Room member indicates. Matt Gilbert, designer and owner of furniture design business Animaro, managed out of Machines Room's premises, gained access to digital fabrication technologies at the postgraduate level first. He got his bachelors degree in architecture in Cardiff and a master's degree "split between architecture and furniture" in Copenhagen (M. Gilbert, personal communication, January 19, 2018). Watching his production workflow for the kinetic lamps with the CNC mill, I asked him about previous manufacturing experience, and whether he had access to digital fabrication technologies during his education. Matt reaffirmed Niki's experiences about undergraduate education and the lack of access to these technologies. His situation changed immediately with the master's program in Copenhagen, where "[they] had a large laser cutter, which could cut up to nine mil[imeter] plywood[,]" and "[he] started using that during [his] first year." (ibid.)

His curriculum in Copenhagen, as it seems, was structured around constant hands-on practice:

My masters was split between architecture and furniture. One of the projects was called One Chair a Week. We had to design and build one chair every week and then destruction-test it at the end of each week. We had a few different size laser cutters, but there was no CNC machine, so I left with experience in laser cutting. There was a 3D printer, but it was very expensive. I never used it. So I left with a lot of laser cutting knowledge, but not CNC and not 3D printing.

But his knowledge and his proficiency were likely shaped by the constellation of machines, workshop space, and human support at the institutional 'makerspace'—what he terms as "facilities":

> *The facilities [in Copenhagen] were incredible. In terms of woodworking and metalworking, there was incredible workshop space, very well-organized, very skilled technicians on site. I hadn't up to that point had the facilities to really make things. So I think that that was probably the most important thing for me was just having space and the facilities.*

But conditions like these—unlimited access to social and technical infrastructures—are not a given for the majority of HE students or other makers. Matt's opportune situation further enhanced with a unique chance he got during his postgraduate studies:

> *A key thing was when I did the internship at CITA, I got access to a laser cutter, like a different laser cutter in a private room, and keys to it, essentially.*[82] *I had to train people how to use it, but it also meant I could use it as much as I wanted for my own work. I got into a habit of kind of thinking through laser cutting basically. I would just sketch something and then instantly make it. So I was lucky in that aspect that I could access that laser quite a lot. I think that was another important thing for kind of getting me into furniture and making.*

The described examples of my interlocutors' makerspace activity and experience as students reveal they are not in keeping with the described categories of the OD&M report. Rather, they suggest that the report initiatives make up ideal conditions which are difficult to achieve. Instead, what occurs are overlapping, hybrid entanglements, none of which should be explained in a deterministic way regardless if that appears as obvious or is actually the case. The entanglements of various circumstances—personal, geographical, economic, educational, technical—prevent causal and reductionist explanations but perhaps suggest how certain elements that appear across most of them intervene with others. For instance, one of the interns at the Copenhagen-based makerspace Underbroen, when I was there was working on a team project to build an ROV and a robot arm for a marine technology education competition in California.[83] The competition challenge was in creating an open-source idea that had no actual pre-existence. As a typical robotics project, I presumed that he studies computer science or engineering, but it became clear that this was wrong:

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[82] CITA together with CITAstudio is the Centre for Information Technology and Architecture of the Royal Danish Academy of Fine Arts Schools of Architecture, Design and Conservation.

[83] ROV stands for a Remotely Operated Underwater Vehicle.

I study production technology at KEA [i.e., Københavns Erhvervsakademi (Copenhagen School of Design and Technology)]. […] Actually, Christopher [one of Underbroen's founding partners] is one of my teachers. So that's how I got to know this place. But [I do] not [have] technical background, whatsoever, besides that. (In: Christensen, 2017)

His degree revolved around new forms of designing for and optimization of production, not about engineering and technical skills. "It's creating all these new maker cultures with[in] classical production," he explains. The specific technical skills, though, he learned from the people around the makerspace: "We have Tom, who has a Ph.D. in something software developing [sic].[84] And with the other electrical guy, [I learn] 3D printing" (ibid.).

While the marine competition appears as the occasion for his involvement in the makerspace, it is entangled to the personal connection with his HE educator. This student is not the only student involved in Underbroen's activities and who has been "recruited" by his teacher and makerspace co-founder. Underbroen's community manager first did an internship with the maker cultures program of Roskilde Festival, which was later followed by an internship Underbroen leading up to his job. But his two activities were not unrelated as Underbroen developed out of the Roskilde Festival maker activities. The point I make here is that student-educator relationships are another form prompting student involvement in makerspaces and digital fabrication. In particular, when educators take on core functions at these spaces. This situation is not unique to Underbroen. At OpenDot in Milan, students and, in particular, students of core staff members often become involved in the activities of the makerspace and its presiding design studio dotdotdot. One of the staff members who teaches at several Italian design institutions has reorganized his workshop curriculum to take place within the makerspace environment as OpenDot's communication manager Laura elaborates:[85]

[A] Lot of students come here, also because part of our team is made by teachers […]. They teach workshops and courses in different universities. We also host part of the program of the workshops here, so a lot of students really come. I think they are the majority of the community. In terms of people that use the fab lab and the machines. […] Maybe because following […] their teacher, then you get along, you do sessions here. (L. Ferri, personal communication, September 12, 2016)

Besides that, OpenDot also collaborates with its student members by letting them co-develop objects and ideas for the different elderly and child care therapy projects in which the site is involved, as well as in their business partnerships like the one with the IKEA Foundation.

84 Name changed.
85 Undergraduate and graduate students from the Milan-based Domus Academy, Nuova Accademia di Belle Arti (NABA), and the Politecnico di Milano, which owns the institutional fab lab Polifactory, constitute the primary user group of OpenDot.

Still, students also leave a negative impression to some makerspace communities, in particular, when they only reach out to them as a place to complete term assignments, thus perceiving these makerspaces as service providers. At WeMake in Milan, students become less welcomed when their action counters the work ethos of the founders and the community, which is built upon a mutual exchange of skills and support. As co-founder Zoe Romano articulates, students tend to turn up around a deadline and expect that their projects could be managed immediately:

> *[S]tudents are more like [they] treat us more like a service. When their deadline approaches and their lab is packed with people, they come here and they want something in three days. We say, "Look. You should come here at the beginning of the year, start learning, and then you have the free laser for you."*
> (Z. Romano, personal communication, September 13, 2016)

Zoe's disapproval of these students' attitude is rather about the way students approaching these places and technologies as if they are handing in a document to be printed in a copy shop for them by someone else:

> *It's a weird relationship with this type of students. So when they come here and they understand what we are telling them, then there is a collaboration. Otherwise, they just go away. So two of them, they came here and they wanted to use the CNC to create a prototype. And we told them, "Look, it's gonna take too long to use the CNC, why don't you use the laser cutter." We showed them how to use it, and they were very curious about it, and they did it, and they worked here like for one month. They did five iterations of the prototype and now they're working with us together. Because we saw the way when they entered the thing. We liked the approach. So when we won the new application for open care projects, we said, "Do you want to work for us?" They did the internship and […] Now they have a contract. So things happen. Yes, but you need to have this mindset.*

The value for her in the maker culture and of digital fabrication depends to a degree on the longitudinal relationship amount in learning how to work with a machine, how to design a file, but also the interpersonal networks that develop within this environment.

'Maker' Prototypes for Mass-Production

> The overall goal of our Hacking Manufacturing month was to explore how to do academic research on the factory floor. Specifically, we wanted to see new outcomes from using manufacturing machines to prototype, rather than traditional prototyping tools. […] *By definition, the prototypes would be production-ready.* (my emphasis)

What reads like a Bauhaus's proposition is a paragraph from a recent report written by the course instructors from another prominent institution, the MIT Media Lab (Ou, Ji, & Dementyev, 2017).

Their report on the annual 'Hacking Manufacturing' course, offered in the Chinese manufacturing center Shenzhen every summer since 2013, substantiates the idea of makerspaces as laboratories or workshops for the development of prototypes for mass-production. Like the Bauhaus, the new workshops for the access to desktop manufacturing technologies enable and restrain at the same time. As the course instructors reflect, "[w]hile we're able to make some tangible pieces with those tools, they're not the kind that people typically use in the manufacturing process" (ibid). Their experience resonates with the issues that the Bauhaus and its students encountered as they attempted to achieve the Bauhaus vision of prototypes for mass-production—incompatibility between the manufacturing technologies and standards, almost but not completely precise production, and prolonged production times. Likewise, it captures the difficulties that makers confront when they try to scale up a project in professional, manufacturing and economic schemes. On that account, I want to illustrate the parallels between the Bauhaus idea and the present situation with two maker-initiated projects that I encountered during my visits to Machines Room, London. The first one, which I briefly introduced in the previous section on students, is *Animaro*, a small design studio for bespoke furniture combining the technologies available at makerspaces and specialists' manufacturing. It encapsulates the path of developing manufacturable prototypes for a contracted and delegated production. The second example looks at the digital knitting platform *Kniterate*, which is delivering a more intricate version of a manufacturable prototype.

The East London-based design company Animaro focuses on connecting art and engineering to build unusual furniture pieces with kinetic elements such as the Crane lamp (see Fig. 2.4).[86] The brainchild of former architect Matt Gilbert, Animaro has been operating out of Machines Room's (MR) premises since 2016. It developed out of smaller projects which he started during his architecture master's degree. He liked to pursue those more rigorously or "scale them up and turn them into pieces of furniture," as he puts it (2018a). The first stage for Matt was going from pursuing his interest as a hobbyist alongside a full-time architecture job to working full-time as a furniture designer out of the makerspace. This process took him nearly three years as he jokingly tells everyone at the inaugural

[86] The Crane kinetic lamp is a scalable mechanical lamp based on a scissors structure technique. The lamp is offered in two sizes—a desk version and a floor one. Matt introduced the lamp design during the 2016 Salone di Mobile trade show in Milan and following its popularity. He launched a Kickstarter campaign in 2017 resulting in his first 50 orders. The floor lamp consists of 36 wooden parts combined with aluminum or brass joints. This construction allows it to be put up at various heights up to a maximum height of 1.9 meters. The wooden beams for one lamp are cut on the CNC mill from one plank. The joints are produced externally by a local manufacturer. On the process of designing and manufacturing the lamp, Matt explained to me that it could be done by hand but it would be less precise in the fitting of the joints due to the high number of pieces. The CNC mill offers the best solution at the moment. While one plank is milled, Matt sands and finishes an already cut one.

meeting of the first Cohort. The Cohort, a pre-incubator initiative launched by MR in the fall of 2017, aims to accompany and mentor long-term resident members such as Matt and other new applicants over a period six months as they develop their specific projects regardless of discipline and objective. The support consists of providing workspace, machine access, peer-to-peer exchange, and public exposure. I attended the first, non-public meeting when both Cohort members and two of the MR mentors outlined how the collaboration would evolve. As part of the introductions, each member commented on a picture that illustrates best their practice and goals and shortly explained to the others what they expected to accomplish and work on during their residency. Matt had sent an image of a factory. He reasoned that he wants to launch his next Animaro product by way of a traditional production chain involving factories and manufacturers.

Fig. 2.4. Crane lamp.

Matt's work practice or rather business model resembles the Bauhaus vision of prototypes for serial production. His motivation for employing maker practices and digital fabrication recalls notable moments from the Bauhaus's product development, or put differently synergies, such as Breuer's steel armchair immediately involving the machines and workspace of Junkers' factories, but also the collaborations of the weaving workshop with different branches of the textile industry. His practice would have been unachievable without the technical and social infrastructure of MR as he frames it

(Gilbert, 2018b). As a starting point, the digital fabrication technologies available at the makerspace ensure that he can iteratively prototype ideas "before outsourcing parts to manufacturers" (ibid.). Machine access, he adds, minimizes risk and, at the same time, accelerates the process from ideation to manufacturable prototype. Otherwise, "[my] projects would likely not get off the ground" (ibid.). Matt's practice-based workflow turns the Bauhaus idea into a contemporary model. I observed Matt over several days working on different tasks such as repairing wooden beams or replacing metal joints, experimenting with a new product (a clock), or communicating with suppliers and potential manufacturers. He would often spend a considerable amount of time explaining to me what he was doing, but also offered a very reflective interpretation of his accumulated process experience as well as his ideal makerspace-factory association. I let Matt's account explain his prototype and product development on its own:

> *As a furniture designer, either you're going to be working with a single factory who is then subbing out a lots of these parts, or in my case, it was working with lots of different specialists. That was something I had to […] to learn. [W]hat I've been doing so far is a case of building a prototype using the tools I have in the makerspace using a CNC, a laser, and the 3D printer, and getting that prototype, I guess iterating it over and over again to get it working better and better and better. There's a point at which you hit a wall because things like tolerance, you can't get something working as well as you would if you get that part made in metal by a manufacturer or something [similar]. Also, if you want a visual prototype, for example, to launch the product, it may be that certain parts of that, they can't be 3D printed. They need to be made in the actual material they would be made. So that you get [..] as far as you can with a prototype, I guess, partly to prove to yourself that it works. You might start showing that to people and get feedback.*
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> *I would make something here, and then I actually exhibited the things that I made using the tools I had here in some trade shows, get feedback, and decide if it's worth pursuing or not at that point, and then kind of go to a Mark I prototype. […] [A]nd then [I] decided that certain parts of it couldn't be made in a makerspace. For example, I was 3D printing the wheel, but it kept breaking [see Fig. 2.5]. I was using a half metal, half plastic composite, but it was still too weak. I don't think it looked good enough, so [I] decided I wanted to get that part milled from solid brass. So then, yeah, I started swapping certain parts out that I knew needed to be properly manufactured.*
>
> *Mark I prototype is done in the makerspace. Mark II prototype involves manufacturers, and then it's a case of launching that Mark II prototype. For example, I normally use Kickstarter to launch a new product, and then during and after Kickstarter, establishing a kind of sustainable route-to-market model for that product […]. In this case with the Crane Lamp, it's that I get all the parts made by other people, and then I assemble them. That's because it's a relatively highly priced item. It's expensive. I'm not going to sell hundreds of them, so it's still more economically viable for me to assemble them.*

However, another route is that you can make the Mark I prototype again in the makerspace, but then the next one, the design-for-manufacturer prototype, you would do with a factory. Either you can do that by creating, let's say a Mark II prototype, which is exactly as you want it to look. That may involve working with specialists to get specialist parts made, but you need to get it looking exactly perfect, and you need a set of drawings, a physical model, and a physical prototype. You can send the map sample and the drawings, or you can just have the Mark I prototype, which is 3D-printed stuff and CNC stuff. It's much more difficult, I think, that route. It's always easier if you've got exactly what you want and then you go to the factory.

There's certain details you can resolve at that stage if you haven't resolved them already. For example, there are certain fixings on something I'm working on now, which are screw fixings, but I think they should be push-fit connections that's done by a machine. It will be very expensive for me to buy that machine now, so I won't worry about it, because I know that will be resolved at that later stage in developing this prototype with the factory. The factory will then, based on your sample and your drawings, they will create a sample. They should do that using the exact production methods they would use for creating whatever quantity you're saying that you're ordering, so if that's a hundred or a thousand or whatever, they'll know what kind of assembly line they're going to set up. So don't let them use a different process.

There's a lot of discussion during that process and pictures that go back and forth as they send it to you. If it's okay, you sign it off. If it isn't, you go visit or you critique what you want them to change. That's I guess the second route. There's lots of other things you have to think about in terms of supply chain. Where you're selling, what the lead time is, all kinds of other stuff, but, essentially, that's how you get from prototype to factory prototype to production.

Fig. 2.5. Elements of the Crane lamp. Photo credit: Animaro.

Makerspaces and digital fabrication technologies for Matt constitute a part of the design-to-production process. However, they cannot replace the entire way of manufacturing objects and the precision of factory production and specialist manufactures. It also seems difficult for makerspaces and digital fabrication to achieve an entirely sustainable production. For his work, however, they provide a twofold value: first, the ability to test parts quickly and make small changes, what he calls "tweaking it"; second, producing prototypes up to a level where one can go to a manufacturer and have them reproduce those in multiples. In the long run, the sustainability of the production for Matt means that he can develop product ideas, prototype them on the ground up to a manufacturable version, and manage sales and logistics with a small team. Once a product design becomes "tweaked" enough, its manufacturing and distribution are delegated to other actors.

The second maker-developed project, which I want to discuss briefly here, is Kniterate. As its name suggests, Kniterate is a digital knitting machine developed by Gerard Rubio and partners out of Rubio's OpenKnit project as a response to the complexity and expensiveness of industrial computer-controlled knitting machines.[87] After three years of experimentation with OpenKnit, Kniterate was launched in London. The knitting machine operates similarly to a 3D printer by turning a digital CAD model directly into a physical product, a knitted garment: "We've simplified the process of designing and making knitwear. Allowing you to go from an idea for a scarf […] into a design ready to be made within a few minutes" (Kniterate). Indeed, the project description elaborates the machine functionality using 'printing' as a reference to the way 3D printers and the pervasive desktop printers work. Like 3D printers and desktop CNC mills, the machine Kniterate aims to fill the space (and market) of the single user and small manufacturers through its reduced size and with the removal of the operating technician. It sits between the basic manual knitting machine and its larger industrial equivalent. As its creators envision, Kniterate empowers its users by enabling the exploration of their "knitting's potential" and the local production of "personalized goods" (ibid.). Kniterate according to its creators is an individualized "reimagination" of industrial technology.

The first machine I saw was their working prototype for its subsequent serial production exhibited during MR's "Fix Our City" installation for the 2016 London Design Festival (see Fig. 2.6). As one of MR's resident makers, the company Kniterate participated in the exhibition. MR assisted Kniterate by providing support with the development strategy, workspace, as well as public exposure of the initial prototype as a soon-to-be included machine in the makerspace's infrastructural catalog.

[87] OpenKnit was a significantly smaller and simplified version of Kniterate as Machines Room's strategic director Nat Hunter explains in a YouTube video. Retrieved from https://tinyurl.com/yckr8mrf.

At that time, Rubio and his partners were still experimenting with mechanical aspects of the machine and trying to figure out how to make it work smoothly. They were collaborating in parallel with textile artists to explore pattern limitations and their reproducibility with the machine. Following a manufacturing phase in Shenzhen in late 2016, Kniterate returned to Machines Room with a so-called "pre-production prototype" (Henderson, 1998a, p. 126) to launch a Kickstarter campaign for the funding of an initial batch of machines in 2017 (see Fig. 2.7).

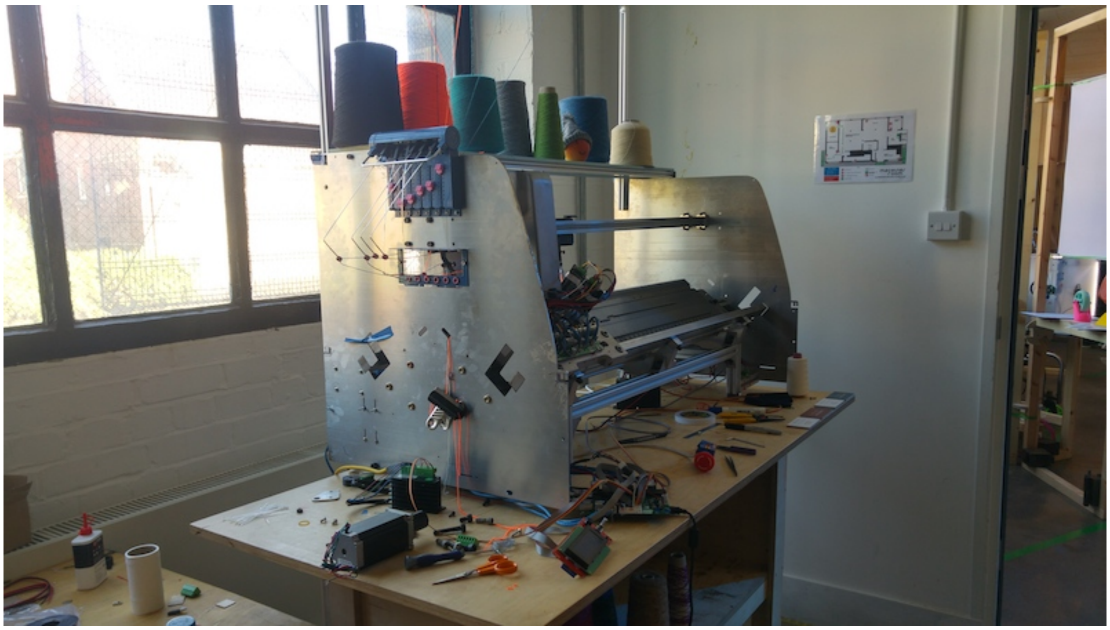

Fig. 2.6., Fig. 2.7. Kniterate prototypes 2016 & 2018 at Machines Room, London.

As a machine and a business project, Kniterate is a development-in-progress which gets iterated with each new relocation from one makerspace (WeMake, Milan) to an incubator (Shenzhen-based accelerator HUB), back to another makerspace (Machines Room), then back again to China, and so forth. In a way, it also prototypes an R&D process of machine manufacturing. This process with all of its stages of progress, failure, delays but also discoveries and updates is documented openly and accessible for their Kickstarter backers and everyone generally interested in the project. As part of that, Kniterate, for example, relaunched their website to include a CAD interface and a community forum, where they can discuss a range of topics with their users: geographical accessibility to a Kniterate machine, questions of functionality, weight of yarns, knitting codes, or the design software. Besides, testing and improving the machine happens as part of the Kickstarter campaign with the fabrication of hundreds of scarves for the supporters. Framed differently, Kniterate not only prototypes its batch production of the machine, but it also prototypes potential garments to be serially produced with the very same machine.

Conclusion: The Old Within the New

In bringing together the historical project of the Bauhaus and the contemporary one of digital fabrication, I have highlighted how the promotion of specific ideas like the creation of workshops for mass-manufacturable prototypes, which both have taken up quite prominently, tends to conceal the infrastructural realities behind them. Moreover, I argued that both the Bauhaus and its contemporary "alternative" have been instrumentalizing not only craft, but also history for a synthetic project, namely for the Bauhaus that of establishing the new profession of industrial design, and for digital fabrication to dispute its unconventionality. Drawing on a discourse analysis of primary sources of some of the leading Bauhaus figures on the school's pedagogical concepts and its conflicting position on the relationship of art, craft, technology, and industry, I described the three often acclaimed positions of leveling hierarchies, specialization refusal, and the workshop vision mentioned above. I have contended that these central ideas have been conflicting and revised all through the Bauhaus history to meet the interests of potentially benevolent partners. I considered these Bauhaus politics as ingrained pretentiousness that remains problematic even almost a century after the school's foundation. As this chapter has argued, the Bauhaus should not be interpreted as a style of design or education only, but as an institution framed by sociopolitical circumstances as well. Rather than rewrite the history of the Bauhaus, I have wanted to demonstrate how the Bauhaus narrative around workshop practice, industry, craft, as well as skill acquisition, accounts better for the empirical analysis of design-situated maker practice in digital fabrication than tracing histories within computer countercultures.

Design's present ubiquity as practice, process, product, and profession is encountered in contemporary discussions on urban reindustrialization through creative industries. At the same time, its endless applicability raises questions of deprofessionalization. The practical examples helped not only understand how Bauhaus and digital fabrication resonate with each other but also to challenge the latter's prospects as enabling reindustrialization and the deprofessionalization of design or manufacturing. The students that I encountered across makerspaces and fab labs usually engaged in digital fabrication for a specific skill acquisition demanded by their studies in architecture, design, or engineering. As sociologists and historians of work have argued skill acquisition is part of professionalization and not the opposite (Abbott, 1988; Sarfatti Larson, 1977). The difference, however, is that learning something in a makerspace remains an uncredited skill or expertise compared to the legitimacy given by a higher education degree. The two maker-developed business projects might not build a representative sample, but the subtle insights from them work to contest the prominent maker tropes. For instance, the imprecision of digital fabrication compared to industrial or specialist manufacturing revealed in Animaro's ambition to scale up. However, also that China remains not only the nucleus of manufacturing but also a prominent prototyping hub for electronics-based technology as Kniterate's R&D and production indicates. The message I tried to convey throughout this chapter has been how it is not only the new but also the old within the new. Thus, in conclusion, I want to recall the arguments of two distinct women: Anni Albers who saw the shortcoming of traditional, mechanical weaving not in its replacement but in the merging with computing (1959), and historian Carolyn Marvin who argues that 'defunct' old practices of technology use contrive new ones as they keep existing in them (1988).

Chapter 3.

Associations of Materialization and Unity in Digital Fabrication

On a bright September Saturday in 2014, I visited the World Maker Faire in New York.[88] Two hours into my visit and I had seen the usual tables and tents comprising 3D printing companies and services, manufacturers and suppliers of electronics, amateur rocket science, and robots of all possible types. What caught my interest, however, was a little jar holding a box with wires submerged in fluid and dirt (see Fig. 3.1). The jar was a working prototype of Wildgrid—a biofuel-based charger for mobile devices that harvests electricity from organic matter such as compost. Being a "rapid prototype," to paraphrase sociologist Kathryn Henderson (1998a, p. 126), the jar did not represent a "pre-production prototype" made with the actual materials and processes used in a final product. Wildgrid's pre-production prototype existed only as design renderings—construction plans and design visuals. These renderings articulated a proximate, pristine idea of the final product. Still, the messiness and intermediacy of the jar prototype contradicted these abstractions of the envisioned design. Instead, what it provided was an instant *materialization* of design accomplished with maker practices and digital fabrication means.

Two years later at OpenDot, one of Milan's makerspaces with a design focus, I was interviewing one of its staff members. Because OpenDot accommodates a considerable number of design professionals, I wanted to know what brought her to this particular makerspace in the city and how she understood the site's specific focus on design. Her reply astounded me: "I didn't know that much about fab labs because I'm actually a designer" (Ferri, 2016). If design in its broadest sense is one of the key foci of digital fabrication, how is it possible that a designer seems unfamiliar with the potentials of digital fabrication technologies, maker practices, and these spaces for design? The historically situated understanding of design as a conceptual undertaking generated by the "Albertian split" between design and construction offers one likely answer (Cardoso Llach, 2015).[89] The distinction

[88] The World Maker Faire takes place on the ground of the New York Hall of Science in Flushing Meadows Park. Without any doubt, this location is chosen for its history of being a host to two world fairs. World exhibitions commission works displaying inventions and advancements by experts in industry and technology, but also in art, design, and architecture. On the contrary, their contemporary equivalent in the form of Maker Faires celebrates "everyone's" ingenuity supported through the bottom-up access to some of the same technologies that have been displayed earlier, for instance, in world exhibitions.

[89] Architectural scholar Daniel Cardoso Llach calls the division between design and manufacturing an "Albertian split" in reference to the work of fifteenth-century Italian architect and theorist Gian Battista Alberti. The split between design and construction work was formulated by Alberti in his exposition *De Re Aedificatoria* (1485, English: *On the Art of Building*) and initially applied to architectural practice. Simultaneously, it marks a long-lasting tradition in Western culture in the privilege

between knowledge work (white collar) and manual work (blue collar) provides another (Crawford, 2009; Sennett, 2008). Still, I assumed that as a designer she is acquainted with the multiple facets of *unity* encoded in digital fabrication. On the one hand, more practically, unity presented itself as the connections of design and production in the same person, in the same technology, in the same space. On the other, more practically, it meant connecting digital/virtual design (bits) with physical manufacturing (atoms) to achieve a cohesive workflow from computer-aided design (CAD) to computer-aided manufacturing (CAM), and, thus, return manufacturing to urban areas.

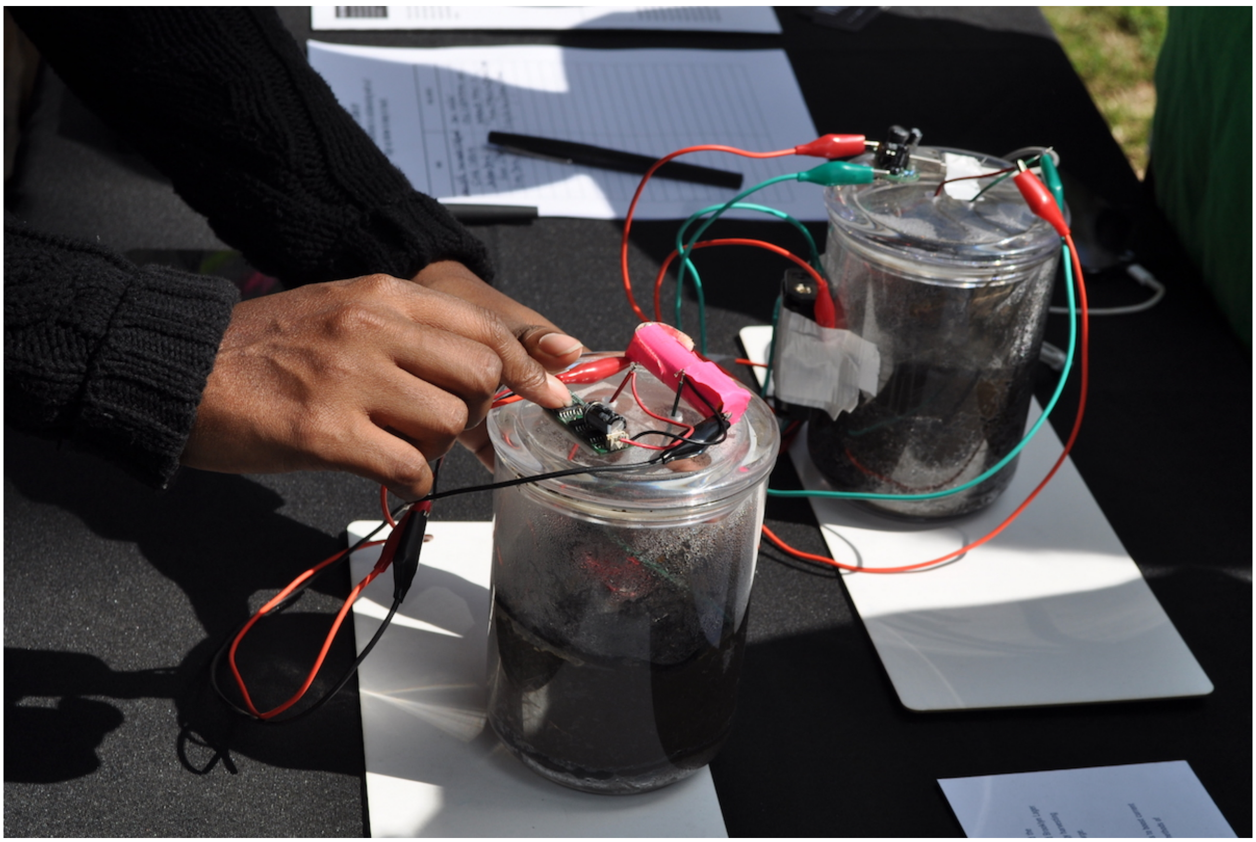

Fig. 3.1. The Wildgrid prototype presented at the World Maker Faire 2014 in New York. Photo credit: Wildgrid website.

Through the connection of physical production of things with "thinking about things," that is their design, as one of my interlocutors' comments (E. Bassi, personal communication, September 12, 2016), making through digital fabrication proposes the reconnection of the seemingly conceptual design practice to small-scale manufacturing. He shares this understanding of digital fabrication as an enabler for materialization with many others. For example, Doug Wittnebel, a principal design director of American design and architecture firm Gensler, states that "[DIY] "[m]aking" uses technology in

of idea/mental over technique/material.

order to create something visible and tangible" (2014). In his *Designlovr* article on the opening of Happylab in Berlin, blogger Ulf Brommelmeier voices that regardless of the professional orientation, be that designer, architect, or photographer, what connects them is the limited access to means for converting ideas into things (2016). Elsewhere, design researcher Jesse Adams Stein argues that despite the celebratory tone of many popular accounts, 3D printing possesses the ability to improve the public understanding of design and production by connecting the extremely invisible design practice to outsourced manufacturing (2017, p. 16). That said, the distribution of digital technologies across disciplines and industries diversified design's orientation from the physical object into "immaterial" avenues such as human-computer interfaces or service design. Put differently, this diversification further strengthened the perception of design as a conceptual practice rather than as one allied with manufacturing. These understandings tally with the two snippets from my fieldwork above. Altogether they foreground specific representations and promises of making and digital fabrication rooted in the two principal themes of the chapter—materialization, and unity.

As my analytical and structural backbone, I draw on their literal meanings: *materialization* denoting the conversion of something into a physical form, and *unity* implying a state or fact of being one single entity (Oxford English Dictionary, 2018). In the context of making and digital fabrication, materialization is revealed most clearly through the ability to produce objects directly and entirely from computer data. At the same time, it uncovers materiality, politics, and infrastructures of practices and processes. The unity attached to making and digital fabrication is one of thinking and doing, humans and machines, but also humans through machines, as well as near and distant locations. Combined, the ideas of materialization and unity through making and digital fabrication enable a conversion "from discrete design activities to complete prototyping or production workflow," as design researcher Roderick Bamford (2015) contends. At the outset, I take the conceptual understanding of design (as a process) to discuss how materialization and unity encoded in recent making and digital fabrication influence design practice and what scope. Indeed, the idea of unity originates in the non-material and abstract qualities of computational design aids for manufacturing as other scholars have shown (Cardoso Llach, 2015; Downey, 1992, 1998).

The objective of this chapter is to situate specific prospects and procedural dimensions of digital fabrication technologies and the respective spaces where these reside. The first aspect considers the prospect of connecting design to manufacturing on different scales such as within one person (the designer), one technology (CAD/CAM), or one place (a shared machine shop).[90] The second aspect concerns the empowerment of makers to pass the threshold to another community of practice or profession.[91] As making and digital fabrication get recognized for bringing about a paradigm shift in design by transgressing traditional dichotomies and their boundaries such as between ideation and construction, design and making, professional and amateur, concept and matter, digital and physical, and so forth (Stein, 2017), I focus on the intersections between them.

On that account, I argue that although digital fabrication and making aspire to materialize and unite design and manufacturing on different scales (personal, geographical, technological), their distinct categories remain separated. Instead, I propose that digital fabrication and making generate *associations* between the distinctive practices and disciplines. I understand association broadly as the connection of things or ideas. An association, however, is also a state of co-occurrence. It implies that a connection entails a disconnection. Thus, I contend that describing these anticipated materializations and unities of design and manufacturing as *associations*—expected connections and probable disconnections—captures the actual practice of making and digital fabrication technologies more accurately. Bringing design and production closer together in one place, technology, or person, is one such expected connection. A different one is the promise of returning manufacturing to urban areas. However, making and digital fabrication reveal potential disconnections. The idea of uniting design and production reappears in the histories of computer-aided design (CAD) and computer-aided manufacturing (CAM). Being in a way a renewed form of CAD/CAM, digital fabrication often places a primary focus on manufacturing as, for example, the mandatory machine training sessions and offered courses at makerspaces suggest.

In the following, first, I emphasize briefly how conceptual design decoupled from the material practice of making translates into the ideas of materialization and unity. Detailed and more precise understandings of design are conveyed in the case studies and observations, where they make the most sense. This depiction provides an initiating framework to unravel the promissory role of

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90 The reappearance of materialization and unity tropes in design influenced by recent making and digital fabrication has also become the subject of several exhibitions in the past few years. For example, the return of the XXI Triennale di Milano International Exhibition (2016) after a twenty-years break was titled "Design After Design" and included various displays of these recent technologies and practices. Likewise, as part of the 2016 London Design Festival, the Victoria & Albert Museum focused on representing how making occurs in design. Other exhibitions, to name a few, include: "Making a Difference / A Difference in Making" (Red Dot Design Museum in Essen, Germany, 2016; "3D Printing: The Good, The Bad and The Beautiful" (The National Centre for Craft & Design, Sleaford, UK, 2017); "Out of Hand: Materialising the Digital" (Museum of Applied Arts & Sciences, Sydney, Australia, 2017).

91 The term *maker* as illustrated in Chapter 1 has become a generic term, which in several instances denotes a different activity than the one practiced by a designer or by an amateur. Rather than meaning that someone simultaneously could be a maker and an amateur, or a maker and a designer, it denotes the common ground between them.

manufacturing for the design practice and profession, in general, and for digital fabrication, in particular. It also sets up the two themes, materialization and unity, for the empirical analysis. I will then present the *expected connections* of design and production as uncovered among my field sites by looking at the aspects of proximity to and restoration of manufacturing. Concurrently, these multiple accounts aim to capture the aspect of cultural positionality of urban politics and geolocations. Based on these empirical accounts, in the final section, I will discuss through a survey of machine training at shared machine shops, an analysis of personal participation at such occasions, and descriptions of digital fabrication as service, how digital fabrication and making foreground a level of *probable disconnections* between design and production, as well as CAD/CAM. Through this discussion, I want to lay out not only some nuances of the unfolding of digital fabrication in the context of (professional) design but also to allude to questions of control and anticipated technical expertise and knowledge.

Deconstructing Materialization

Making in the broadest sense indicates itself as a process of materializing the concepts that design produces. This idea originates in an understanding of design as a conceptual and immaterial activity distanced from the material renderings of physical manufacturing. A range of factors has shaped such primarily Western understanding of design (Jones, 1970). First, the long-standing mind-body dualism indicated in the superiority of drawing over construction established forms of labor division and with that a distinction in classes rather than communities of practice.[92] Second, the introduction of mass-machine production with the Industrial Revolution further reinforced and expanded the division of labor. Last but not least, the implementation of scientific approaches such as rationalization and specialization to design in the wake of cybernetics and system thinking espoused the role of design for non-fabrication functions (Halpern, 2014). The way these distinct yet intertwined aspects modulate how design is practiced, trained, and perceived is beyond the scope of the chapter. Nevertheless, in analyzing the idea of materialization, their influence reappears in the different proposals on making and digital fabrication. As such, it is necessary to interpret and inquire carefully into the power they exert.

However, understanding design as conceptual is somewhat inaccurate as design scholar Claudia Mareis maintains, because it marginalizes the material foundations of design, the technical procedures

92 The mind-body dualism or duality is a view in the philosophy of mind that the body and the mind are distinct and divisible. In the Western tradition, the mind-body duality is shaped by the philosophy of René Descartes.

involved in that, and the specific tools for drafting (2014, p. 47). The quotidian practices of scribbling and sketching on paper, of model construction, but also the materiality of the computer-aided design are beginnings or steps of a materialization. However, they are not the full realization of manufacturing. What then comprises (the notion of) materialization? To expose the inherent assumptions and contradictions, as noted, I work with the literal meaning of materialization as the conversion of something into a physical form. It is precisely the capacity of creating physical things through digital fabrication and making that acts as pertinent for design or architectural practice as architecture scholars Benay Gürsoy and Mine Özkar point out (2015). The linking environment that is computational tools for material production accessed through making and digital fabrication, they argue, devises "a renewed role in design thinking" (ibid., p. 30). For them, making framed in a digital fabrication context requires a redefinition of making's place in design as a mediator "between the ideation, representation and materialization processes" (ibid.). Following sociologist John Law, then, "To understand mattering of the material, you need to go and look at practices, and to see *how* they do whatever reals that those practices are doing, relationally" (2010, p. 174; original emphasis).

Design studios, for instance, often display representations of design as visual renderings of their ideas and projects. Makerspaces, on the other hand, display material works-in-progress, finished prototypes, or final products made by their members regardless of their background (see Fig. 3.2). Being made and remade digitally, the conceptual design representations, in this case, are seldom on display as they attest to being intermediary steps of the CAD/CAM workflow. Their constitutive making tends to follow a trial-and-error approach much like the craftsperson's approach. The difference in the execution of this process between makers depends on where the individual experience is situated on the professional–amateur spectrum. For example, amateur makers will likely download an open-access CAD file from an online platform such as *Thingiverse* or *Instructables*. The fabrication then might follow the provided instructions. Possible modifications might entail the adaptation of CAD files and models to the local technical infrastructure.

Fig. 3.2. Exhibiting members' projects and materials at WeMake, Milan.

In the case of the laser cutter, for example, instead of creating a new CAD model each time, followed by modifications to the CAD file based on the design visuals before the final "cutting" of the object, amateurs tend to follow an experienced-based 'cut-and-see' approach. That means that if the entire cutting fails or cut pieces appear incompatible with another component, amateur makers will likely make minor changes on the downloaded CAD file, which is then reprocessed to the laser cutter. These intermediary steps, especially the modified files, remain undocumented and incorporeal unlike their equivalents of printed design visuals. Still, much like amateur makers, professional designers also dispose of the "physical manifestations of (interim) results […] [as] they gradually lose their value as the design evolves further," as the philosopher of technology Sabine Ammon reminds (2017, p. 497). Design theorist John Christopher Jones notes that design drawings replace the product "as the medium for experiment and change" by reducing risk (1970). Professionals bringing the experience and knowledge of preparing a design for fabrication will likely create their CAD files through a multiplicity of design renderings that allow for testing without their actual physical fabrication. This approach descends from a long tradition of a disintegration of design from production that allows for a recurrent promise of materialization to prosper without a recognition of the mundanity, situatedness, and relations of the socio-technological practices behind that.

Digital Fabrication's Conveyance of Unity of Design and Production

Digital fabrication and the contemporary maker culture reintroduce the notion that the same person can execute both conceptual practice of designing and its materialization by manufacturing. In her analysis of the political imaginaries of 3D printing—the opportune 'killer app' of maker culture—Stein confirms this common characterization of bringing about unity: "The idea of 3D printing appears to neatly collapse the boundaries between designer, manufacturer, distributor, and consumer into one role, bringing irresistible immediacy to the prospect of bringing the virtual into the material world" (2017, p. 6). The potential of uniting design and production via and within digital fabrication technologies, however, is not novel. It extends previous promises and narratives of CAD/CAM technologies as revealed in the anthropological and historical examinations of their development and implementation in the professional context of mechanical engineering (Downey, 1998), architecture (Cardoso Llach, 2015), and design engineering (Henderson, 1998a).[93]

In *The Machine in Me* (1998), an ethnography of CAD/CAM's development, distribution, and specific application to engineering education in the 1980s, anthropologist Gary Downey tackles how leading commercial companies portrayed the technology as a rescue.[94] It allowed the user of the technology to "overcome the boundary between design and manufacturing […] by bringing […] [them] together inside the computer" (1998, pp. 3-4). At the same time, this technological fix for identities by taking "possession of manufacturing activities" (1992, p. 161) was one of national significance promising to improve the status of the United States (US) as an economic leader, what Downey calls the "doctrine of competitiveness" (1998). The framing of this technology as a

93 The idea that old technologies reveal ideas about new ones has been countered by two futurological tropes—"supersession and liberation"—as Paul Duguid describes (1996). Supersession refers to an idea of remediation, i.e., every new technology absorbs its predecessors, while liberation presumes a technology's right of being free. Duguid, however, takes issue with this unity of ideas as they likely conceal conflicts.

94 On the portrayal of new technology as a "panacea," in this case numerical control (N/C) in the machine tool industry, see David F. Noble, *Forces of Production* (1977), pp. 218-220. In Noble's account, the promise for "technical graduates" came in a vertical power delegation towards on the managerial ladder: "New technologies would bring them more status and leverage and, equally important, would allow them to indulge their professional infatuation with state-of-the- art gadgetry" (p. 218).

sociopolitical and economic benefactor, he notes, erases the actual transformation that happens through its implementation (ibid.). Speaking of "positional identities," Downey argues that CAD's promise to designers is "to take possession of manufacturing activities" by rendering away the agency of the others (1992, p. 149). For the industry, he notes, the technology promises to break down "the 'brick wall' between design and manufacturing" (1998, p. 14)—a desire shaped out of the clear distinction between both and the privileged status of design. Hence, according to his longitudinal ethnography, the idea of unity becomes pure rhetoric of power and control irrespective of the implementation.

The understanding of CAD and numerical control (NC) as a power mechanism by which work is delegated into the machine outlines Daniel Cardoso Llach's historiography of CAD systems *Builders of the Vision* (2015). For Cardoso Llach, the Western tradition of elevating mind over matter plays a pivotal role in how design comes to be understood. Brought together with practices of drawing and devising such as the Albertian split, the tradition assigns authority to design and in the book's case of architecture — the authority over building. For architects, the introduction of CAD/CAM technologies meant regaining power over construction by "collapsing the distance between design and construction" as well as "re-gain[ing] their lost status as master builders" (ibid., p. 31). The use of CAD/CAM by architects affects the particular "positional identities" of the drafters. As Cardoso Llach shows, architecture and designing were perceived as creative endeavors, whereas drafting was a technical operation, thereby allowing to be automated.

Apart from the creative aspect, CAD/CAM frames design as a linear process as Henderson points out in her multi-sited ethnography *On Line and On Paper* (1998a) of computer graphics' application in design engineering companies. Focusing on the role visual representations such as sketches and drawings played in the communication process of design engineers with the shop floor and how their digitization altered that, she argues that the anticipated integration of design and construction (or manufacturing) actualized on some levels only (1991). The unity of design and production within one person, in this case, a unity of the work of engineers and drafters employing CAD technology remains futile. The engineers using CAD she observed developed the creative and conceptual work, while the drafters maintained an intermediary position by being tasked to translate the engineers' creative results into more precise and realistic instructions for the shop floor. Like Downey's account, her observation reconfirms that production is entirely outside the framework of design engineering with or without CAD/CAM.

By stressing do-it-yourself as the practice ethos behind digital fabrication, however, the potential of unity overlooks some of those failed promises of CAD/CAM in the past, but also the degree of possible achievement. Two variations counter the idea of unity. First, a maker who downloads a CAD file from an online repository instead of creating it but executes the fabrication themselves. Second, a maker creates the CAD file for manufacturing themselves but delegates the fabrication to someone else or service providers. Recalling the forerunners of contemporary descriptions of digital fabrication in this section, I wanted to highlight how one aspect of *associations*, that is expected connections, invokes broader questions of control. The perception of making or of its historical variations above as a counter-practice to design returns comparable interpretations of what their unity might signify, who might benefit from that unity, how it might attain, and how that is emphasized. These analytical insights together with those on the notion of materialization guide my empirical discussion in the following section.

Expected Connections of Design and Production

The idea of reducing, even removing entirely, the distance between design and manufacturing has been on the agenda of making and digital fabrication from the start on. Anderson (2012) contends uncritically that the recent developments would make it possible for "garage tinkerers" to put ideas immediately into production. In a 2008 roadmap, the Silicon Valley-based non-profit Institute for the Future professed that in the future makers and manufacturers would be linked if not interwoven.[95] This rationale has also been implemented into local, national, and even transnational political charters with some of them confirming the spirit of Downey's "doctrine of competitiveness."[96] This section, then, focuses on how the practitioners I met during my fieldwork make use and recreate this idea, which I present as *expected connections* of design and production, within their own personal, professional, and geographical context. Similar to the charters above, I split these expected connections into two scales: first, enabling *proximity* between design and manufacturing on a personal, technological,

[95] According to the roadmap, "[i]n the future, traditional manufacturers and maverick makers will be closely linked—sometimes cooperating, sometimes competing, but frequently blurring the boundaries that separate them." See Institute for the Future, *The Future of Making: Roadmap* (2008).

[96] Local and national activities to name a few include the *Crafted in Vienna* competition, initiated by the communal Vienna Business Agency, the association and foundation *Make in Italy,* which represents the interests of Italian makers and makerspaces, but also administrative interventions like the US presidential initiative *Nations of Makers*, or China's governmental backing up of makerspaces as incubators and innovation hubs (NESTA, 2016). Multiple transnational projects as part of EU-funded research frameworks have been implemented with policy objectives: broader overviews of the maker movement (Rosa, Ferreti, Pereira, Panella, & Wanner, 2017), or multi-sited studies the maker communities and their collective potentials for open design and manufacturing (Lobascio et al., 2017; Menichinelli & Ustarroz Molina, 2018).

procedural, and spatial level; second, the rendition of this into a sociopolitical and economic level as an idea of returning (urban) manufacturing.

"So, It's Like Everything Is Very Close" — Cutting the Distance to Production

Proximity presents itself not only as a spatial or geographical concept. Many of my interlocutors, understand proximity as process acceleration. As such it devises an immediate advantage for the time-constricted industry of design. Accelerating the process of designing a prototype, for instance, works by the ability to iterate multiple times as Happylab Vienna's fab lab manager highlights:

> *When you're creating a design, and you realize that this and that doesn't fit. Then I just go to the machine and do it again. Redraw it and make it over again. And I can quickly try different designs. For example, we can produce PCBs [printed circuit boards], and in that, I see a great advantage [of DIY making]. Because producing PCB nowadays costs a fraction […], it is more expensive to produce it here. But the benefit is that I can have it made in twenty-thirty minutes. And every PCB needs to be amended. Something needs to be redrawn; something needs to change.[…] I can design, manufacture, and test a PCB within a day and see what's wrong, and then manufacture again. This extremely accelerated opportunity is [beneficial].* (Jung, 2016)

In other words, accelerating the design process comes with the ability to iterate on the ground. Iteration is a central procedure in design. The addition to the iterative process of designing, however, is what I call participatory material production as the opponent to traditional distributed manufacturing. Acceleration, for Happylab's fab lab manager, means also fabricating a finished prototype or product without a prolonged production chain. In particular, public access to additive manufacturing simulates a direct experience of industrial product development by "shortening the production chain" (Bolzan & Mortati, 2015). For the technical manager of MakeWorks Toronto, a co-working space with an embedded prototyping lab in Toronto's West End, "being able to get that [a 3D print] back, turns out is extremely valuable for people who are doing that [design]" (D. Starck, personal communication, May 26, 2016). Also, as he puts it, proximity minimizes risk: "[…] the old style of working was find your model, get your prototype completely ready, and then send it, and three weeks later you get it back, and it doesn't fit."

From a different perspective, iteration vis-à-vis acceleration by means of digital fabrication and DIY making constitutes a distinct technique for OpenDot in Milan. Unlike a typical makerspace or fab lab such as Happylab, OpenDot is a workshop attached to the interaction design studio dotdotdot, which grants external members access to its socio-technical infrastructure. Their distinct technique relates to the many different projects that dotdotdot carries out within the OpenDot facilities, which simultaneously sits on the threshold between dotdotdot's design studio practice and OpenDot's infrastructure. As such these projects might include regular members of OpenDot (the fab lab) unaffiliated with the dotdotdot (the studio), or the studio staff operates the technical infrastructure of the fab lab to accomplish them. One such design research project, for example, focuses on elderly care and child education. Conducting this care-related project within the confines of both fab lab and studio becomes possible through "the technologies and this thinking of 'make things happen' quite quickly because you can prototype, produce, experiment, change, and then [repeat it] again" (Ferri, 2016).

The relationship between the proximity to technologies, the possibility to iterate multiple times, and the shortening of the traditional production chain converges in a trajectory such as from idea to prototype. The fulfillment of this trajectory with the means of additive manufacturing is considered to bring on a paradigm shift in design. In this context, I recall a conversation with the community and makerspace manager Mikael from Copenhagen makerspace UNDERBROEN around preferred digital fabrication technologies by their members and generally the broader applicability, especially of 3D printing:

> *So he [a member building geodomes] started down here actually at the same time with me […], and he, of course, had all the drawings and ideas and so on, and then he teamed up with one of the older members […], who's really good at 3D printing. And I think actually within four months […] they actually managed to do this iterative design process, where they prototyped so many different stuff […]; they actually found out the final design, and now they are ready to kind of produce it. So that to me… it's such a big building project or design project. It's kind of unique that you can go from an idea and some sketches and drawings to actually a full prototype within four months.* (Christensen, 2017)

As Mikael had a different disciplinary background than design, architecture, or engineering, he adds that for him fabrication with 3D printing consists of downloading a file from a platform like Thingiverse, tweaking that a bit, and then printing it. He calls the result of it producing "mainly plastic, rubbish." Although for him this fabrication process is questionable concerning the material significance, reciting a recent tech article on scientists who had successfully 3D-printed an ear, he sees it as opening up new perspectives. However, these are prospects of a proximal future shaped in scientific laboratory environments. Instead, the reality in this makerspace, and in many others, keeps multiplying plastic prompting Mikael to question the application of 3D printing as his choice of best cases indicates. While his account of the sustainable construction project and 3D printing overall recalls the benefits of participatory material production, it also invokes an idea of socio-technical imaginary (Flichy, 2007; Jasanoff, 2015). The imaginary becomes validated when one reads

UNDERBROEN's subtitle: "tomorrow's manufacturing workshop."[97]

As the current director of OpenDot and longtime practicing designer and design educator, Enrico's account differs. He likes to speak of "DIY design." In asking about his experience in "DIY design" and how digital fabrication and the collaborative spaces influence it, Enrico replies that "it's [DIY design] useful when it empowers people to solve the first part of the design process" (Bassi, 2016). Within a professional design context, this hints that a reversal of the direction through making and digital fabrication enables more appropriate co-design or participatory design approaches. He describes the design process as a two-fold construction: "It's knowing the problem you want to solve and how to solve it." Enrico explains this to me with an example from the previously mentioned child education and care projects at OpenDot (and dotdotdot):

> *When it's helping the therapist to explain us or to work with us on the design process of a tool that she needs. That's incredibly powerful. Much better than hoping as a designer to see the problem couple of times, realizing the solution and being able to do the perfect job, and complain if the client is asking to modify.*

The challenge is one of acknowledging that "DIY design" misses the benefits of a traditional industrial production chain, that is supply and distribution, certifications, manuals, maintenance, and customer service. Similar to Bolzano and Marti's description (2015), "DIY design" targets the smallest entities—single or small design companies and producers. He contends that "[h]oping that someone, just because of the passion he has, is able to manage all these things; it's a bit naive" (Bassi, 2016). What he proposes instead is that making, digital fabrication technologies, and the spaces where these can be carried out, facilitate the ideation and probing of ideas:

> *What a fab lab can do is to speed up the process of developing something new, [be]cause it empowers the people who know the problem to communicate, test stuff, modify stuff, hack existing objects, check if the idea is good or not, and so on. So the entire beginning, let's say the roots of the development.*

However, counter to the many (speculative) accounts of making and digital fabrication as collapsing the distance between design and production, Enrico's account manifests a variance or as I call it a probable disconnection. Enrico presents the contemporary developments in the two terms—"DIY design" and "DIY production." The two are intertwined, making it at moments impossible to know whether they have distinct properties or overlap completely. "DIY production" in Enrico's

[97] This description has been changed to "tomorrow's prototype and pre-fabrication facility where traditional craftsmanship is combined with modern digital production technologies." According to Wayback Machine, the change happened on March 2th, 2018. Retrieved from http://underbroen.com/ .

understanding appears as an involuntary result of "DIY design," as he critically describes, for instance, the facilitation of fab lab-related workshops as events:

> *We do a workshop just to do an event. Even if you're building something during the workshop, you start from the point [of] knowing that what you're gonna make is not gonna work. And people will just take it, bring it home, and throw it away after a while. And it's okay. Everybody knows that nobody says that.*

What he underlines here is the questionable significance of making and digital fabrication. By putting a strong emphasis on potentials and opportunities of these spaces and the technologies for labor and economic revival, for example, several critical issues become obscured. Examples include the difficulty of handling plastic pollution as a result of additive manufacturing, the problem to reuse plywood leftovers—a limited natural resource—after milling or laser cutting, or the increasing hazards for human health and environment with the growing number of electronic components on the DIY market.[98] As Stein argues, 3D printing like other technologies "is a mutually constitutive system within and beyond design […] [a]nd it also exists as an ideological concept as well as a technological system" (2017, p. 17). Recalling Downey's argument about technological hypes (1998), then, we need to consider carefully envisioned problems and what forms these could develop. In Enrico's words, the ostensible playful approach behind DIY and making could enhance the ignorance of sociotechnical issues:

> *While DIY production, in this case, more than designing, is incredibly helpful to explain to people that things require an effort and you should limit the number of things you make. Or, on the other hand, what actually happens is that people create products in a fab lab, designed to never be finished. […] Constant work in progress, updating. You know the double face of the situation. We will face this at a certain point. And then again that's the difference between, of course, DIY design and DIY production. And in Italy, it's very strong, because of the design culture we have. So designers here are sort of artists. […] So the designer is the one that cut the divine gift of creativity and good taste, and is creating these chairs that are amazing objects, not necessary working that well. And I'm a designer, so I'm talking about a category I know. The main point is that in this case DIY design helps to explain to designers, well, that they have to listen to the customer because the customer is at least partially designer… is at least partially involved in [the] design process.*

In other words, for everyone involved in a co-design process both, "DIY design" and "DIY production," are educational prerequisites about consumption, framings of problems, and considering solutions beyond the most conventional ones. Still, the same way Enrico disunites design from

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98 On the environmental aspects of making and digital fabrication, see Kohtala, 2015; Kohtala & Hyysalo, 2015; also on the relationship of environment and care for the environment within makerspaces and hackerspaces, see Foster, 2017.

production within DIY, making, and digital fabrication, as opposed to connect them, he maintains a position of proximity with many of the others. The promise for him is one of shortening the "distance [of] where you produce things and where you think about things" with a potential of returning production (to urban areas), but not "work you do by hand."

Returning Production

The relocation of manufacturing, also known as de-industrialization, transformed many Western cities from centers of industrial production to partial centers of service production and distribution. For the design of low- and normal-priced physical products, it meant outsourcing their entire manufacturing (including prototyping), resulting in a long and partially risky production chain which further fortifies the disconnection from making. To balance this loss, many cities began redefining themselves through new forms of service-based production including the so-called "creative industries" (Hartley, 2005; O'Connor, 2007). In recent years, several accounts proposed a possible reinvigoration of local and urban production through the accessibility to desktop manufacturing technologies within makerspaces and fab labs (Gershenfeld, 2005; Richardson & Haylock, 2012; Richardson, Elliott, & Haylock, 2013). Many communal, national, and transnational economic programmes, policies, and research networks keep replicating these promissory narratives.[99] Enrico's comment that "[i]t [digital fabrication and making] could definitely bring back the production, but not work you do by hand" (Bassi, 2016) falls along these lines.

How is this idea translated across the different sites and cities considering their distinctions? Can the return of manufacturing—a form of materialization—gain significance beyond reductionist debates on labor? Also, if work, then who performs it? These questions help situate the following examples of urban production extracted from my empirical data. The vignettes in this section are taken from interviews, makerspaces' media presentation such as their websites, and external research projects, to introduce and discuss urban production on three different scales: first, local or communal; second, national; and, finally, what I refer to as heterogeneous.

[99] See examples in footnote 96. From the perspective of local economy, a recent study on the impact of the maker movement onto urban economic development argues that city planning finds making interesting for its dependence on "physical density" (Wolf-Powers et al., 2017).

Among the included sites of my study, Copenhagen-based UNDERBROEN is the only space describing itself publicly as a "laboratory for local and urban production."[100] Returning production to the city or at least the promise of that distinguishes Underbroen from the other local shared machine shops: Fablab Nordvest is a living lab-type of makerspace in the city's north-west; Copenhagen Fablab is a communal fab lab run by the municipal organization Kultur Valby in the south-west; Labitat is a members-run hackerspace in Frederiksberg, a former independent municipality within Copenhagen, and, finally, DUOP is a co-working space and workshop in the former industrial harbour of Christianshavn in proximity to Underbroen. Besides indicating a great availability of spaces in Copenhagen and their good dispersal, this brief overview also presents every single one's objective.[101] It further helps contextualize Mikael's rationale on Underbroen's specific focus on production and what production means for them:

> *If you want to follow the Fab Lab charter which we have actually applied for, […] you should have some degree of open access to everybody. And we haven't had that before because it's a membership-based maker space […]. We are very much focused that people should have the opportunity to run businesses from down here, and to do actually productions. […] [A] lot of the other makerspaces, […] here in Copenhagen are not allowed to do any kind of production because it's, yeah, it's more kind of an association and funded by the municipality and so on.* (Christensen, 2017)

The delineation between the different shared machines shops in Copenhagen responds to the much-needed multiplicities within maker culture. At the same time, it foregrounds the question whether providing the means to return manufacturing, makes open access by the public incompatible with professional usage? In other words, it makes unity questionable. In a sense, local and urban production, in this case, care less about the ability to prototype and manufacture on the ground, but about legitimizing potential economic prosperity. As mentioned in the previous section, however, the space had changed their description from "tomorrow's manufacturing workshop" to "tomorrow's prototype and pre-fabrication facility where traditional craftsmanship is combined with modern digital production technologies."[102] Perhaps such updates reflect the aspect that accomplishing manufacturing demands aligning the standards with industry. Often these shared machines shops are incompatible

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100 Hereafter, for the sake of reading clarity, I will write UNDERBROEN in regular letter case: Underbroen.

101 The city of Copenhagen according to its most recent census in January 2018 has a population of around 770,000. Having five publicly accessible shared machine shops makes Copenhagen stand out compared to other cities. It also makes the goal of urban production sound less utopian. While notably, Milan and London have a higher number of spaces, their population is markedly greater.

102 See Underbroen's website: http://underbroen.com.

with them, thus making the goal of returning urban production unattainable.

As stated above, Underbroen is located near Christianshavn (Christian's harbor). As a former working-class neighborhood, Christianshavn developed an unconventional and hippiesque reputation since the 1970s. It also has become one of Copenhagen's larger homes for creative industries such as advertising and architecture, as well as hosting the Royal Danish Academy of Fine Arts. Being the home to the creative industries makes itself visible in specific attributes such as a high-density of coffee shops, smaller boutique, or artisanal and organic food stores—all symbols of a prosperous lifestyle. These places have often displaced traditional craft business and manufacture by replicating a present-day romanticized image. Surprisingly, I still discovered a few small craft workshops. Their physical location in the souterrain of residential buildings allows for direct exposure to the practiced work practiced in there. As I recalled this sight and having expected perhaps more of an office type of creative work, I asked Marie, the managing director of Copenhagen Maker, what role city politics play towards both the sustainment of traditional craft and the revival of manufacturing with digital technologies.

Copenhagen Maker, a local version of the Maker Faire franchise established in 2016, and Underbroen are entwined in a range of activities. Both developed out of the well-known Roskilde pop music festival as a partnership between a small association of people, members from the festival, as well as the local municipality.[103] One of Copenhagen Maker's objectives besides running a public event is researching the application of practices and approaches of maker cultures and digital fabrication for urban development, thus turning Underbroen into one of their field sites. The research goal originates in the partnership with the Copenhagen municipality as Marie tells me. Returning to my question on city politics, sustainment of tradition, and future ambitions, Marie responds that Copenhagen's politics are less deliberate about these developments:

> *[…] if you look in other cities than Copenhagen there's [a] tendency for these makerspaces [to be] placed outside the cities, where you see that the inner city [and] small city centres, they will kind of suffer from this. Copenhagen is a bit different. Although, we still have areas where you can find okay-cheap rent for small craftsmen […]. But […] I wouldn't say that it's a political decision. Some [people] in the municipality are trying to work for this. For instance, like in here [Underbroen, with the idea of] local production and that.* (M. Mogensen, personal communication, February 14, 2017)

[103] Initially called MADE, it was renamed to Copenhagen Maker to distinguish itself from the eponymous Manufacturing Academy of Denmark, a joint initiative of industry, finance, associations, and education. Retrieved from http://en.made.dk/about-made/.

She also makes a connection concerning labor and economy between local and national politics, craft traditions, and the global developments put forward by information and communication technologies. The maker scene of Denmark for her is "still quite [a] small-scale thing." For her, it originates in Denmark's status as a welfare state creating a sense of social and financial security, thus decreasing the need for people to create their jobs. The lack of a specific need, for her, means that Copenhagen's maker culture develops at a slower pace compared to larger urban areas in countries like the United States or Germany. At the same time, it removes the primacy of technology to establish 'new' models of work, production, and cohabitation by escaping the competition inflicted with the pace of tech and innovation-driven economies. Instead, it entitles to explore how long-standing traditions of craft and hand-making collaborate or synthesize with digital fabrication technologies, as she suggests:

> *[O]ver time this [Underbroen] is going to be [a] space where ... We've been working with this [concept of] zero to maker, maker to maker, maker to market, or maker to scale. And this is what we are interested, in the maker to scale. […] [H]ere it's people living off what they are doing. And it's also a part of making a new labor thing. People can earn what they need for having a living for themselves. And not ... maybe … not want to be [part of] a huge company but just want to do what they're doing for a living. So this is also part of a local production, new ways of finding labor. In a new market where […] where you don't have to scale. […] [I]t's just not because you have some kind of idea […] with hacking or stuff like that. Other spaces do that.*

The specific local context of Underbroen and Copenhagen Maker which intertwines with Denmark's politics, histories of craftsmanship, manufacturing, and industry, as well as the legacy of Scandinavian *sloyd* pedagogy, makes Underbroen's update of their description even more comprehensible.[104] That said, the entanglement of these aspects but also the overlapping goals of Underbroen and Copenhagen Maker reaffirm what Enrico from OpenDot indicates. As he points out, the idea of local production encoded in making and digital fabrication is not about working with hands, although this gets frequently taken as the entry point or benefit of making and digital fabrication.

National — Scotland, March 2017

While the previous example of return of production considers the immediate local surrounding, other places and initiatives extend to a national level. The best known example of linking digital fabrication and maker cultures to questions of urban re-industrialization is *Nation of Makers*, a network of

[104] *Sloyd* or slöjd is a reformed craft-based pedagogy developed in Finland in the mid-nineteenth century and distributed across Scandinavia, Germany, England, and the United States. It was conceived for a general rather than vocational education. Today it remains part of compulsory education in the four Scandinavian countries.

activities and follow-up strategies initiated by the White House during Barack Obama's legislative term.[105] Like the Danish version with their communal partnership which emphasizes the role of craft tradition in Denmark, *Nation of Makers* focuses on a long tradition of heavy industries in the US, scientific innovation and the American ingenious spirit. Tradition, however, serves as a narrative to celebrate the positive results of the US industrial or Denmark's handcrafted past. Rather, the expectation is placed on the contemporary technologies, practices, and movements. Blending the past with the future in the present was also the plan of the Glasgow-based charitable organization MAKLab. Co-founded by the architects Bruce Newlands and Richard Clifford in 2012, MAKLab included three locations until its sudden closure in summer 2017.[106] MAKLab's location in the Charing Cross Mansions provided a range of desktop manufacturing technologies and workspace to the local community. Their second location in Glasgow's Commerce Street, then, focused on offering access to industrial manufacturing machines and processes, as well as commissioned manufacturing. Their third and smallest one was based in Dumfries, in the south of Scotland. MAKLab's ethos according to their website declared that, "We believe that Scotland has a bright future, but like much of Europe has struggled to maintain the practical skills, expertise in manufacturing, innovation in materials and learning systems that much of our economies were founded on."[107]

Despite MAKLab's primary locations being in Glasgow, the organization had started before its bankruptcy to accomplish part of their future plans of expanding across Scotland. This idea foresaw the creation of a network of geographically dispersed spaces: "we're in talks at the moment with Edinburgh, Stirling, Dundee, Paisley, possibly Inverness, and we've put a proposal for a mobile unit as well" (D. Rand, personal communication, March 2, 2017), Dylan, one of the studio mentors, discloses. Taken together, these cities not only span a geographical network over most of Scotland's territory but they also cover the country's various industrial traditions: Glasgow was UK's second powerhouse, in particular, in shipbuilding and the marine engineering industry; Paisley was a centre of the weaving and textile industry; Dundee was the center of global jute industry; Inverness was known for distilling; and Sterling and Dumfries were market towns focusing on agriculture. After their

[105] The *Nation of Makers* initiative includes the first-ever hosted Maker Faire at a governmental building—the White House Maker Faire in 2014, the National Week of Making connecting public institutions such as libraries, community centres, schools, but also communities, as well as an updated proposal for the Strategy for American Innovation. Retrieved from https://obamawhitehouse.archives.gov/the-press-office/2015/10/21/fact-sheet-white-house-releases-new-strategy-american-innovation.
[106] MAKLab abruptly declared bankruptcy on August 21st, 2017, and has terminated all activities.
[107] Retrieved from http://maklab.co.ul/. The website has been taken down with only a message about its insolvency remaining. For any details before the bankruptcy in summer 2017, the website can be accessed through Wayback machine: https://web.archive.org/web/20170719152710/http://maklab.co.uk/home.

deindustrialization, these cities refocused on high-tech industries such as health in Inverness or Paisley, or service and creative industries in Dundee or Glasgow. In addition, Dundee received the recognition as UK's first UNESCO City of Design in 2014. This diversity demands acknowledgment within the respective local makerspaces as Dylan points out: "It's going to be different in each location because we don't think one map plan fits all. […] Each place will specialize in something else, and then all their skills will develop different communities." The concept behind that is also known as distributed manufacturing. Distributed manufacturing describes a form of decentralized manufacturing based on a network of geographically dispersed manufacturing facilities coordinated through information technology such as file sharing, servers, and cloud networks. It further represents a form of local manufacturing as practiced in the historic cottage industry or in the homes of consumers. MAKLab's vision creates a hybrid between an information technology-supported form and that of the cottage industry:

> *[W]e have to do like initial research, and we'll use kind of the basics of everything [i.e. standard set of machines represented at makerspaces] to see what the community is interested in. Then, as they get more interested in one direction, or if we're partnering with someone who's very interested in a direction, we'll work towards that. So, we're hoping that there'd be kind of distributed manufacturing, so we could ask Paisley to help us out with something that we couldn't do in Glasgow and Edinburgh to help with something else.* (my emphasis)

The recognition of interests and local particularities, whether historical or emerging out of the reorientation of cities towards creative (service) industries, is framed within their goals for "a future of manufacturing in Scotland." But for MAKLab the national scale of returning manufacturing is not confined by political strategies and narratives such as those of the *Nation of Makers* program. As a charity, it rather looks at creating a symbiotic effect to help its members and the local communities find out how and where they might fit in a global technology and innovation-driven society. It attempts to connect people with a higher degree of digital skills with people who miss those for a variety of reasons but know, for instance, how to cast iron, dye fabric, or work with a lathe. It denotes in a sense a more sustainable and socially-oriented approach of returning manufacturing to urban landscapes:

> *[G]enerally […] we're not linking so much the past. We're not going like, 'We're going to be building loads [of] more boats.' We're not going to build a new shipyard. It's [rather that] we have a lot of people with a lot of good hard skills that could still be put to use. Just need to be more open to learning new things as well, so things like knowing welders. Take that as a shipyard reference. Their skills are still useful and necessary for a lot of things and it can be used in the spaces. We do have welding down at Commerce Street. Hopefully, the future kind of manufacturing is going to be a bit more distributive. It's going to be lots of people working together rather than being a huge kind of Goliath. […] I don't think*

we're linking the past so much as we are kind of saying these things are still necessary and [to] some degree it just needs to be channeled differently. We still hope to be building big things, but probably a different scale and different ethos as well.

While MAKLab focused on providing access to digital fabrication machines and spaces to work, as well as connecting local communities of practitioners from different backgrounds to revive Scotland's manufacturing future, another Scottish initiative, Make Works, aims at connecting what has remained of the country's manufacturing industries with the contemporary non-fabricating creatives through an open source digital platform. Unable to find the practical infrastructures for getting things materially fabricated, Scottish product designer Fi Duffy-Scott started mapping out manufacturing websites and companies across the country. Following a research phase, she initiated a round of residencies for artists and designers at local manufacturers, during which they contributed to the manufactures with things such as helping improve the manufacturers' marketing. In return, the local makers provided infrastructures, machine, and process training for the creatives to develop their projects. The result of Duffy-Scott's initial research and the residencies was the development and launch of an extensive digital platform in 2015, which provides information about manufacturing aspects such as turnaround times, costs, facility access, materials, processes, available machines but also company histories. In the meantime, Make Works has expanded from the digital realm to the physical. In 2016, it opened their first manufacturing workshop in Birmingham, UK, which serves as a training facility, a liaison between makers and local manufacturers, but also to enable local prototyping and manufacturing.[108] What started as a personal project of Scottish product designer Fi Duffy-Scott during her studies at the Glasgow School of Art is now transferring to other countries as well. According to their website, Make Works has received multiple inquiries from cities and regions in Europe, the Middle East, South America, and Australasia to adapt the model to their specificities. The first two launched in 2017: in Sweden so far it offers a digital platform, while in the United Arab Emirates it provides both virtual and physical service by being hosted at the contemporary art organization Tashkeel in Dubai.

Heterogeneous — The Boat Community at London's Regent's Canal, September 2016

The third scale of returning urban production conveys little of the economic or political overtone of the previous two. Instead, it recognizes the value of making and digital fabrication as well as the related

[108] For more details, see Make Works' Birmingham workshop website: https://workshopbirmingham.org .

aspect of proximity within a different problem-solving capacity, namely that of repair and maintenance. If repair and maintenance are designed as part of a production chain, they make up forms of manufacturing and production. This understanding descends from the idea that manufacturers are simultaneously providers of additional components and conveyors of considerable merit of expert (production) knowledge. Several scholars have explored a diversity of ethnographic projects and communities of practice to illustrate the necessity and the role that repair and fixing reveal as alternative strands of making and digital fabrication (Jackson, 2014; Foster, 2017; Rosner & Ames, 2014; Rosner & Turner, 2015). In my case, I call this a heterogeneous scale of urban production attending to supplement and assist communities, practices, and processes at the same time.

When I first visited Machines Room in East London, the makerspace had prepared an exhibition for the annual London Design Festival called "Fix Our City." The exhibition displayed projects by members and by other London-based initiatives and enterprises to exemplify how new models of citizen participation and makerspaces transform urban life.[109] One of the projects that caught my attention was a tilted wooden boat—a punt as I learned much later—displayed in one of the makerspace's workshops behind a window (see Fig 3.3). In front of the window, the caption read "Ross Andrews: Reconnecting with the Regent's." Each display included a tiny plate explaining what is being fixed and giving background details about the project. Ross's caption stated the following:

> In his multidisciplinary project, Reconnecting with the Regent's, Maker in Residence Ross Andrews is delving into the history of the Regent's Canal waterway network and experimenting with sustainable, affordable living, *looking for solutions which support the boating community* and are replicable more broadly. It is fixing things, materials, processes, systems, and attitudes. (Booklet, my emphasis)

[109] Some examples included local maker-tech companies such as Technology Will Save Us, SAM Labs, Sugru, Kniterate, and OpenDesk.

Fig. 3.3. Wooden punt reconstructed by Ross Andrews from blueprint through digital fabrication at Machines Room, London.

As the exhibition happened over a week, most of the projects with minor exceptions were not accompanied by their makers. Fortunately, I saw someone next to the punt in the workshop who turned out to be Ross himself. We briefly chatted about his project and his experience to arrange a longer conversation for a later time. The following summary and analysis of this heterogeneous scale are based on my interview with him, which I conducted a couple of months later.

Ross has become a long-term maker-in-residence at Machines Room. He uses the space on a regular base for both personal and job-related projects. When I first saw the punt, I thought this is the work of either a carpenter or someone with highly professional skills. Interestingly, though, he revealed that he is neither a designer, nor a carpenter, nor any other professional immediately associated with creative industries. It turned out that his background is in environmental consulting which as he explains connects to his approach to fixing and making things. The boat I saw was a long process of learning how to turn old blueprints into digital formats by modeling them in 2D and 3D software, how to cut with a CNC router, and ultimately how to assemble a full boat. As such, he told later that it was an attempt to demonstrate to the local boat community what access to desktop manufacturing and digital practices of production offer to them as opportunities:

You've a got a project on a boat and you've got a room or a space full of kit (sic), and partly I wanted to […] to work out how to connect Machines Room better with the boating community. The boating community is generally hands-on and likes fixing things, or a lot of people on boats mainly out of necessity, and I thought that Machines Room was a really good space for them that most of them didn't really know about. So, I thought the start point would be to try and work out some projects on the boat that would be translatable or usable by a bunch of other people on boats, as well as dealing with the specifics of the boat. So, I've taken bits of the engine apart and I've re-paneled the engine room using… I've had to model bits of the boat to get the various shapes and cuts. I've got plans for various things using the laser cutter. I haven't come up with anything that uses a 3D printer yet. But in terms of the punt project, the boat that you saw that I built, it was partly the idea that it would be good to have a little tender for the narrow boat. […] I was really keen to learn the CNC cutter because I think it's a very useful tool, and I'm bad at learning things unless I'm doing something real. I can't make up a project for no reason at all. That seems […] a waste. So, I needed a real project. Punts just… it had been floating around, a design someone had given me. A friend's grandfather was a boat builder and I grew [up] in Stratford-upon-Avon, where they have punts on the river […]. [T]hree or four years ago, when my friend's grandfather died, […] she gave me a copy of his punt plans, and I just then forgot about them. […] I suppose the stars aligned when I'm thinking about making a tender for the narrow boat, and Machines Room were taking part in a makerspace raft race. So, they needed some kind of floating contraption made and I wanted to learn the CNC machine and a bit of 3D modeling and work out how you could get old school plans into modern files.

Machines Room is located right at the Regent's Canal in London's East End which connects the central neighborhood of Islington with the river Thames.[110] As such it has been a vital focal point for local manufacturing for centuries. It also hosts London's most extensive housing boat community. However, the more London becomes the global economic center, the more of inner-city production and repair disappear, hence living on a boat bears a challenge. The visible presence of vessels along the Regent's Canal speaks to Ross's suggestion to connect the needs of the boating community with the provisions of Machines Room. This perception of urban manufacturing is not exclusive to them but reveals that within the discourses on the impact of making and digital fabrication on re-industrialization a sense of care through a practice of repair, fixing, and maintenance remains sidelined.

Probable Disconnections of Design and Production

In the previous section, I foreshadowed specific ways how making and digital fabrication frame possible connections of design and production by associating them with the broader sociopolitical

[110] As I am writing this section, Machines Room announced to their membership the closure of the current location on 45 Vyner Street in East London at the end of April 2018. Although a new location is in the planning as their technical manager told me, it has not been revealed where it would be.

questions of re-industrialization, onshoring, but also with local traditions to ensure their sustainment. These associations are also accomplished through the functional operations of digital fabrication, the technological practice, as well as their comprehension. On that account, if making and digital fabrication are expected to connect design to manufacturing, then there ought to exist latent disconnections between them as well. The practice suggests a contradiction: that neither a materialization of design through making, nor the unity of design and making is attainable in full scope through the processes, practices, and technologies of digital fabrication. In other words, they allow for passing the threshold between making and production or amateur and professional, but not transgressing the boundary between them. The combined access to CAD through specific software applications such as the proprietary Fusion360 and Rhino3D or the open-source options Blender and Inkscape, and to CAM through additive manufacturing machines, laser cutters, or CNC mills and routers, within one physical space, namely that of makerspaces, fab labs, or hackerspaces, suggests that it translates into a united workflow. But are making and digital fabrication reconfiguring this? How are makers familiarizing themselves with CAD/CAM as a connected workflow?

Underpinning much of the digital fabrication technologies employed by designers and amateurs alike, CAD/CAM offers a probable site of disconnection. While the entire process appears as united, the path of learning it is far from that. Broadly defined, CAM is the application of software for the control of machine tools in manufacturing. In more precise terms, CAM is a system comprising the design of tool paths in the respective software for execution by the machine, also known as computer-numerically controlled (CNC) machines, as well as the machine operation for manufacturing. As such, this process requires mandatory training provided by staff or technical volunteers at shared machine shops. Put differently, the machine training becomes an "obligatory passage point" (Callon, 1986). This training, however, often detaches CAM from CAD by concentrating on CAM solely. One common explanation for this practice is that makers know how to prepare a computer-aided model. This model, however, is not automatically equivalent to a model for CAM. The aim of this section, then, is to reveal this inherent contradiction by focusing on the obligatory "technological" passage point of skill acquisition for members of makerspaces and those inquisitive about it—the machine training. In addition, it reviews the idea of service as an affiliated aspect of digital fabrication. Digital fabrication as services takes many forms: from designers preparing CAD files and having service providers or even makerspaces fabricate for them, to completely intangible chains of production through virtual 3D printing or laser cutting platforms, where all you have to do is upload a file and wait for the delivery of the fabricated file.

On Learning CAD and/or CAM, Not CAD/CAM

Both CAD and CAM each make up one part of the entire digital product development activity within the product lifecycle management processes.[111] As such they are often used together or with other computer-aided technologies (CAx) integrated as stand-alone products or modules. Within the realm of maker cultures and digital fabrication, these can put just as 2D and 3D design applications (CAD) and the characteristic maker manufacturing machines (CAM), that is 3D printers, laser cutters, or CNC mills. Although CAD developed out of CAM, Downey and other scholars maintain that "the history of CAD/CAM had become the development of CAD/cam" (1998, p. 17; Cardoso Llach, 2015), with a spelling of CAM in lowercase to emphasize that the technologies fell through in achieving a unified process; instead, they strengthened the superiority of design. This situation, at least regarding how one acquires CAD/CAM prowess, remains consistent in my observations of making and digital fabrication. In other words, what is taught for something complex as CNC milling? Are these different technologies and processes understood as a single workflow or as intermediary steps that start where the previous ends without much overlap?

Taking these questions and the idea of unity into account, in the following, I will first briefly introduce the historical development of CAD and CAM. I will then present a short survey of typologies of machine training offered in makerspaces that I carried out based on website information and conversations with staff to discuss how that relates to the CAD/CAM workflow. The survey examines what most spaces offer as additional courses to be booked by members or externals as well as the mandatory machine training sessions. Based on this survey, I will then describe three distinct models of training in the respective machines as I experienced them through my participation. These models range from "not even CAM or CAD" to "full workflow."

Introduction to the Development of CAD and CAM

As outlined earlier in the section on the unity of design and manufacturing, CAD and CAM have a longer shared history which will be discussed regarding context-relevant themes. The full history of CAD/CAM is beyond the scope of this section and chapter.[112] Developed as numerical control (NC) technologies for primarily military use at the MIT Servomechanism Laboratory and Parson Corp. in

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111 In industry, product lifecycle management (PLM) is the process of managing the entire lifecycle of a product from inception, through engineering design and manufacture, to service and disposal of manufactured products.

112 For a more detailed history of numerical control (NC), CAD/CAM and automation, see David F. Noble's *Forces of Production* (1984); also Reintjes, 1991. For a non-US account on NC and CAD/CAM, see Rader, Wingert, & Riehm (eds.), 1988.

the 1950s to 1970s, CAD/CAM grew its popularity in the 1980s with the broader commercialization of the technology. The Servolab, according to the electrical engineer and computer scientists J. Frances Reintjes (1991), envisioned the entire design and manufacturing process "as an information processing sequence," ideally carried out through the use of digital (numerical) methods. As part of this development, the Servolab focused for the most part in the 1960s on CAD applications and interactive computer graphics. On the long run, the laboratory foresaw a direct interaction between designer and computer turning the technology into a design tool. Downey reconfirms this development noting that before the 1980s CAD referred to use of the computer in design regarding number crunching for heavy calculations (1998, pp. 13-18). CAD/CAM in a similar manner appeared as referring to computer graphics. It was not until the early 1980s that CAD/CAM came to signify the merging of these two separate instances, that is "the appropriation of computer graphics for productivity in design and manufacturing" (ibid.).

The newly developed workflow missioned to collapse the design and manufacturing divide. However, this should not happen by letting the human work with the material, as Cardoso Llach explicates, but by reducing the burden and moving that to the machine:

> […] the replacement of the human was presented not only as a step towards industrial optimization, but also as a form of emancipation: a way to "free" people from the toil of dealing with materials, "liberating" them as creative agents. The natural conclusion of this logic of gradual automation is a single mind designing and sending the machine in a seamless mental transaction—a designer that resonates in contemporary discourses centered around rapid prototyping and 3D printing. (2015, p. 47)

Despite the popularization of this thread by commercial vendors and tech journalists, as Downey notes, the prospect of unity failed. The transformation into a cohesive technological process that assigns equal control on both sides of the design-manufacturing border occurred only in design (in CAD), not in manufacturing (CAM). In the process of drafting automation, CAD takes over the agency of manufacturing people with the ability of certain 3D technologies to translate a geometric model into manufacturing operations (NC like milling or machining). For Downey, "[w]here before they [manufacturers/shop floor workers] stood at least separate from design, if not equal to it, the stabilization of NC Part Programming and perhaps other manufacturing activities within CAD threatens to make them directly subordinate" (1992, p. 161). At the time, CAD was often used to produce digital versions of hard copies of drawings, which were re-entered by the CAM operators as manufacturing information, thus constraining a direct communication between design and manufacturing regarding one system for all.[113] As Downey maintains, there was no smooth transition from design to manufacturing as a CAD/CAM workflow. Instead, the workflow remains split up into CAD and CAM. Moreover, he contends that the predominant positive image of CAD/CAM in the 1980s diminished the range of interpretation of this technology. For him, making critical remarks on the promises of CAD/CAM over topics such as labor displacement, redistribution of power upwards, reduction of hands-on skills, expensive equipment limitations, meant going against the mainstream view of American progress by technology. Similar tendencies, which I have first-hand experience with, can be observed in the context of making and digital fabrication.

Forms of Maker Training

Makerspaces and fab labs put a great deal of stress on training and acquiring technical and creative skills. While the principles of learning by doing remain in the foreground, as these sites evolve and build a more extensive and diverse membership, they often require from their members to pass a specific machine training. The training offered is as methodologically and structurally diverse as these spaces could be. There is not one single approach to this. Most obviously, the mandatory training ensures that members familiarize themselves with basic machine settings, as well as learn about safety measures to prevent any harm. From this perspective, then, the most reasonable training would be that in machine operation. To put it in other words—providing basic knowledge in CAM. However, if CAD is prerequisite for CAM, where goes the CAD component in the nexus of CAD/CAM? Is learning CAD in times of downloadable files becoming obsolete?

These questions led me to survey in detail the forms of training, the workshops, and the courses offered at my research sites. This composite survey is by no means exhaustive and cannot provide a finite typology of makerspace training. However, as at least some of the European sites are connected with one another, share similar experiences and resources, thus presupposing a particular repetition of practices. The survey data is based on the sites' public presences, that is homepages, newsletters, public online calendars, social media, and event announcements. As such, these information sources constitute a point of reference for members and newcomers besides the actual interpersonal interaction within a space. I was interested in the particular descriptions they give on the theme of training. The survey mapped how my studied sites present the following aspects: 1) form of training, 2) duration, 3) prerequisites, 4) targeted participants, and 5) level of distinction between CAD and

[113] On the reverse function of CAD drawings, see also Henderson (1998a).

CAM. The timeframe covers from my initial contact with a specific site at the beginning of 2016 to summer 2017. The survey helps contextualize the descriptions of my interlocutors on machine training as well as my personal experience gathered through training participation.

The common denominator regarding training between all these sites are the specific machine introductions.[114] These are usually divided into the four types of CNC processes—3D printing (additive manufacturing), vinyl cutting, laser cutting, and CNC milling. The sites use different labels to describe that: Training, Introduction, Orientation, and in the UK-based sites, Induction. In non-English speaking countries, the given title often translates to introduction or training.[115] These naming strategies show, however, little detail of what is being taught or trained, and the level of complexity of the respective CAM technologies. Instead, the time dedicated to a training session becomes a first indicator of the complexity of CAM technologies and the allocated level of detail. The time assigned for mandatory guided training varies significantly from one space to another and from machine to another. A vinyl cutter, for instance, requires little introduction into its operation process: from loading the vector file on the connected computer to executing the actual cutting. On the contrary, understanding the technical doing involved in CNC milling exceeds this minimal involvement. Therefore, the variations in time spent on training suggest how much or how little of the CAD/CAM unity could be ascribed to digital fabrication and maker practices. Combined training in CAD and CAM is no exception, but also not the rule.

For example, Happylab (in Vienna and Berlin) follows the principle of introducing the particularities of each machine process within an hour strictly. In this one hour, a member or any other participant familiarizes with the digital interfaces of the CAM application and the machine via a Powerpoint presentation. In the remainder, the instructors will briefly show the basic machine functions in front of the machine itself. This demonstration excludes hands-on training. The participation in this training grants permission to a member to use the respective machine. Fab Lab Berlin has developed a two-hour training session for 3D printing and laser cutting that ends with a test. This test proves the person's ability to operate the machine. Distinguishing these training sessions

114 Despite the embedded complexity of these computer-based digital technologies, people at most sites refer to them as machines. This offers interesting hypotheses about them: that their naming aims at removing technological fear, especially, when these sites are further equipped with traditional wood lathes, woodworking machines, and the like; that despite their digital nature, what they do is much more tangible than the virtual environment of their close relatives—the personal computer.

115 In one case, at Milan's WeMake, the Italian word used for the training is *Abilitazione*. *Abilitazione* derives from the Latin words 'habilitare'/'habilis' and means "making fit, suitable, skillful." The far more common understanding of *Abilitazione* nowadays is the process of academic habilitation or passing an exam for professional qualification. The machine training provided here portrays precisely this dual meaning of the word *Abilitazione*, as I will show later.

from regular workshops requires that participants come prepared. For test preparation, they provide an online repository with learning materials on the specific machines. Thus, what they hope to achieve through that, as a former fab lab manager reveals, is having more one-on-one time with each participant to learn the machine. In both examples, the processes explained to members are entirely CAM-related. In most cases, makerspace instructors and managers assume (and expect) that a participant will have a CAD-file prepared or downloaded. For the complex CNC mill, Fab Lab Berlin runs, for instance, half-day or full-day workshops that aim to show a unified CAD/CAM process by starting with the creation of a model on the computer before the actual manufacturing. Machines Room in London follows a similar approach to this intensive training. Here learning how to work on the ShopBot PRSalpha CNC mill takes up a full day course, though giving no immediate access to the machine after its completion. Following the course, a participant is required to book at least one supervised session with a staff member before working by themselves.

The duration of these training further translates into the content taught and the level of detail. In many of the short sessions, a machine introduction only covers the absolute basics of CAM and tends to disconnect training from CAD. Participants will learn how the machine works and how to load their prepared files for printing and cutting. The ability to design and to prepare 2D/3D CAD models might be expected from the potential participants and members of a space, but this cannot be taken as a given for everyone. Some of the spaces recognize this issue and response by offering separate courses for the preparation of 2D vector graphics for laser cutting and CNC milling, or for modeling for 3D printing. Outsourcing CAD from CAM adheres to the idea that these spaces attend to a seemingly expert user group.

Still, a six-hour course titled "Modeling for 3D printing" makes no promise to teach all variations of 3D modeling, nor to delve into the fine grains of 3D printing. It serves the specific purpose of providing a detailed introduction to the steps and operations of computer-aided design for 3D printing. A sample course usually features the introduction into a specific modelling software: most often the proprietary Fusion360 or an open-source alternative such as FreeCAD or TinkerCAD; its specific user interface and virtual workspace; some basics of parametric design; file setup in the 3D slicing software Slic3r or Cura; and depending on the participants' knowledge further operations and commands of parametric design. Time permitting these courses attempt to include the actual printing of the created files to present the virtues of rapid prototyping—the iterative, near real-time prospect of own manufacturing. Likewise, the training in a CAD application presents an overall starting point for a newcomer in this environment. Machines Room, for example, considers their software classes as a suitable entry for beginners: "We teach most of the software you need to know to start designing for our machines, even if you're an absolute beginner you can start here."[116]

As mentioned already, the duration of a training session or course depends on the machine type. The median duration for 3D printers, laser cutters, but also CNC mills, is often around three to four hours. These average sessions, depending on whether their focus is on CAD or CAM, aim to achieve roughly an eighty-twenty ratio of each content. In the "Modelling for 3D Printing" course, for example, the twenty percent give enough time to load a file on the 3D printer, set it up, and print a downsized version by the course instructor. Machine training, on the contrary, begins with brief discussions and advice from the instructors on the creation of the CAD files, that is design considerations such as how to create splines, assembly connections, or file exporting parameters. This seems to be the practice in all places, where participants are expected to operate the machines by themselves. However, at two of my sites—Make Works Toronto and Makerversity London, which are also co-working spaces, members cannot learn to operate the in-house CNC mill. While other spaces invest time and effort to train members, here, the house technician performs the CNC milling. Members provide only a CAD file and return to pick up prefabricated elements. Although this represents a particular case of detachment not only of CAD and CAM but also of the essential hands-on aspect of making, the connection between CAD and CAM is perhaps the strongest within the training for large CNC mills.

CNC mills are by far the oldest digital fabrication technology. With their variations in size and application, they bring several perils for users, thus turning a training into a much more extended and advanced experience. The personal hazards vary: from physical injuries on the person operating to a financial burden caused by false cuts (of plywood), and thus an overuse of machine time. As for 3D printers or laser cutters, mistakes and debris of the process are often the results of misunderstanding the interplay of CAD and CAM. Therefore, CNC training considers this aspect at the greatest. Spaces such as Machines Room or WeMake equipped with large CNC mills attempt to encompass CAD and CAM as much as possible during their full-day training. Their instructions and support include topics such as how to create a basic CAD model, reflections and tips for the creation of a CNC design, the setup of tool paths from CAD files, teaching basics of G-code programming that controls the machine, the machine interface itself and its setup, safety measures, as well as material studies. Where CNC training is slightly shorter in time, the sessions only cover basic skills for machine operation and

[116] See Machines Room description of software classes on their website: https://machinesroom.co.uk/learn-2/.

either supplement it with a separate course such as "Getting Used to CNC Cutter," or one-on-one support by the makerspace technicians.

Accounts of Dis/Unity by Training

Machine training differs between each space as the previous section shows. There is no uniformity in the DIY paradigm. The spaces, their staff, or managing members interpret that differently. This sometimes leaves their members' little options on how to acquire specific skills. I share this experience made during three training sessions on three different machines at three places. By using these examples, I want to reconstruct in hindsight the understanding of CAD, CAM, and CAD/CAM that I developed through that. This opens up questions about whether making and digital fabrication succeed to unite design and production, and CAD and CAM. It also puts into question the presumed knowledge and skills, but also how a general idea of the expert user remains the norm for technical work.[117] The first example of 3D printing comes from my attendance at the weekly hour-long machine training at the recently opened Happylab in Berlin. The second one—laser cutting—was part of a structured, regular training session offered by Fab Lab Munich. The third case of CNC milling is a monthly hands-on introduction, which I attended at Munich's Haus der Eigenarbeit. While the physical location of these spaces is in Germany, they follow different practices and philosophies reflected in the attainment of the unity idea.

3D Printing — Happylab Berlin, October 2016

I had visited the Vienna location of the Happylab franchise previously. Therefore, I had a sense of the space arrangement, concept, and training model. However, I had not participated in one of them. The monthly training in a specific machine happens at the end of the weekly Wednesday evening tour of the space. There is no obligation to participate in the training after the tour or vice versa. Still, I joined both of them. Despite the dreadful October weather, there were about twenty people for the tour and almost twice as much for the following training session. I attended a few of these double sessions and usually, most of the tour participants stayed for the training session as well. This appeared as a logistical challenge to me as both laser cutter and CNC mill were housed in smaller separate rooms, where barely ten people could fit in. The 3D printer was placed in the central area, which had minor occupancy limitations. Still, I wondered how are we going to be trained on the machine with so

117 On the idea of expert users in technical work see Orr (1995), also Barley & Orr (1997).

many participants at once? For all three machines, the training begins in the central area, where one of the fab lab managers gives a PowerPoint presentation on the technical details of the CAM software and the machine interface. This approach, in my opinion, appears as paradox considering the hands-on inclination of DIY.

As we arranged around the few desks for the presentation, the fab lab manager began with a brief overview of the content, followed by an introduction into additive manufacturing and other related processes. As additive manufacturing processes are material-bound, she highlighted that the 3D printers at Happylab work only with ABS.[118] Up to this point, the presentation showed no details about file creation and preparation in CAD. One participant, then, asked where they could get a 3D printing file and the fab lab manager referred them to the online platform Thingiverse. She noted that she had downloaded a small vase from Thingiverse to use as a model reference for the training. The model file helped her to go through the specific steps, which in Happylab's particular case consisted of uploading the file in the printing program Catalyst and sending it off to the printer. For other technical specifics, participants were then referred to check the fab lab's Wiki for manuals. After the lecture, we walked over to the 3D printing station. The training finished with showing us how to place the printing plate correctly, load the file, and then cleaning the printing supports in an alkaline bed.

The Happylab franchise uses only professional 3D printers. These printers allow no "tinkering" with them at all. The only interaction on the machine interface is reduced to loading the printing plate as well as starting the print. The model they use guarantees a high quality of 3D prints but limits to a maximum the interaction between human and machine. In this specific instance, training was a very inanimate experience and taught little to nothing of a unified CAD/CAM process. Indeed, when it comes to 3D printing, this particular space, and its two related locations are perceived by their local and wider competition as a "printing shop"—nothing more but a service provider.

Laser Cutting — Fab Lab Munich, April 2017

"You come for the 3D printer; you stay for the laser cutter." I heard that many times from makers and staff members. Laser cutting most easily allows to pass the threshold from design to production, but also from amateur from professional as the variety of laser cut accessories sold on Etsy or in popular pop-up stores suggest. Frankly, I find laser cutting uninspiring—the results are flat, with wood or

118 ABS is the abbreviation for Acrylonitrile butadiene styrene, common thermoplastic polymer. Lego bricks are made from ABS and are often used as a reference in makerspaces when they speak of the physical qualities of this 3D printing material.

cardboard you always have burnt edges, all is based on vector graphics. Regardless of my personal preferences, the CAD/CAM technology behind laser cutting is complex yet approachable, thus giving me no reasons to avoid it. Although I have had many small hands-on introductions in laser cutting at different makerspaces, I wanted to participate in a mandatory members' training that certifies me that I can use the specific machine. I chose a session at the Fab Lab Munich based on a couple of factors stated in the description: the limited number of participants (only five), that we would learn how to prepare designs for the laser cutter, material studies, and configurations, as well as the machine itself.

The training took place on a weekday evening. Being a small group, the instructor started the session with a round of personal introductions. Besides the one person who had brought with them a CAD file and a material to work with, the rest of us participated out of interest. Still, one participant stated that they are intrigued by the technical features of the machine—an Epilog Zing 6030 CO2 laser cutter. Following our brief introductions, the instructor explained the general physics of lasers, somewhat scientifically instead of with tangible examples. Moving on to a discussion of different materials that can be laser cut in general, and with the laser cutter at Fab Lab Munich in particular, he commented on the experiential type of knowledge required for material setup. Where needed he demonstrated mechanical components of the laser cutter such as the vector cutting grid. We briefly skimmed through the laser focus, reset options for presets, and laser parameters before delving into the CAD portion of the training.

Although the training description on the fab lab's website recommended bringing our laptops, there was, first, no indication about CAD software, and, second, the entire training was structured as a screen demonstration on the computer workstation connected to the laser cutter. As we all sat at one table, the training portion on design preparation was performed as a lecture. This lecture seemingly intended for those bringing knowledge in designing and vector graphics covered only technical specifications: the size of a drawing, size of lines, splines, and hairlines (h-lines). Through a software demonstration in CorelDraw—the vector graphics application used by the fab lab—these specifications and other file functions such as uploading and importing were explained briefly. Though CorelDraw served as a container for other applications, we were advised to start with the open-source option of Inkscape. The remainder of the CAD demonstration focused on CAM-related technical functions: the difference between cutting and engraving, how h-lines and color define cutting or engraving, speed, power, and frequency setups, the limitations of micro-level measures, lost information, and human readability of tool paths (G-code).

In the final part of the training, the instructor asked us to prepare a 'Hello World' graphic based on the demonstrated design path, which we would then laser cut. Constrained in time partially by the unstructured and uncoordinated training session, the group decided to jointly design the small 'Hello World' lettering. Once done, the instructor showed us briefly the safety and calibration steps that we have to keep for working securely and independently. As we began with our hands-on practice, we were left unsupervised with the laser cutting. This concluded the proposed three hour-long CAD/CAM training session. In retrospect, I argue that this training comprised aspects of CAD and CAM, but neither one extensively, nor as a united enterprise.

CNC Milling — HEi Munich, December 2017

Over five weeks I participated in one demonstration and three training sessions in CNC milling. These four distinct sessions gradually increased the implementation of a full CAD/CAM workflow, thus connecting design directly to manufacturing. Working with a CNC mill is effectively the most complicated process in most digital fabrication spaces. Compared with 3D printing and laser cutting, CNC mills are conceivably the only machine requiring "real" CAM in the usual sense. Besides that, 3D printing could be technically considered as "CAMless" since the slicing software automates the CAM completely.[119] By contrast, training in CNC milling involves a multiplicity of steps and layers: 2D or 3D modelling in a CAD software; export of a CAD-model in a CAM-readable format; inspection of the model's manufacturability and if necessary modifications of the latter in the CAM-software environment; preparation and virtual simulation of milling with the CAM software; the generation of the computer-readable tool path instructions (G-Code) for the CNC mill; initial setup of the CNC mill and the material for milling; follow-up adjustments of material, model, and/or G-code; safety precautions and supervised milling; post-milling treatment and assembly of material. Such a multiplicity represents the so-called CAD/CAM workflow which connects designing, in particular for manufacturing, with the actual fabrication process. Digital fabrication spaces rarely provide training with such an intensity and intention.

It was my third and final training at Munich's Haus der Eigenarbeit (HEi) that demonstrated how CAD/CAM, as well as design and fabrication, can be united within one person. I participated in a course called "Introduction to CNC-Technology."[120] As mentioned earlier in the "Forms of

[119] I like to thank Garnet Hertz for pointing me to the interpretation of 3D printing as "CAMless."

[120] It is difficult to translate Haus der Eigenarbeit correctly. Perhaps the closest to the German meaning would 'House for Personal (DIY) Work,' as Eigenarbeit's literal translation is 'active work.' The concept behind Haus der Eigenarbeit is to use space, tools, and if needed supervised guidance, to complete projects by oneself.

Training," the duration of a training session is an essential detail that reveals how much CAD and CAM should be expected. This monthly course limited to four participants is a six-hour long comprehensive and unlike other training sessions is a very interactive and hands-on experience. This brief sequence of course elements can only give some account of all that:

- *Round of introductions;*
- *Introduction of HEi-Tec-Workshop area (i. e. high-tech workshop) and the different CNC machines by Benjamin;*
- *Description of the construction of HEi CNC mill (self-made) and the CNC process;*
- *Detailed introduction in the history of G-code, programming in G-code;*
- *A short exercise in programming a geometry in G-code with simulation on a small desktop CNC which uses a pencil as a milling tool;*
- *Introduction in CAD/CAM workflow with local software (Draftsight & Sheetcam);*
- *Preparation of CNC milling on the machine;*
- *Exercise on the last two elements: CAD vector model based on two wooden pre-cut blocks for the creation of a small box (see Fig. 3.4), the definition of CAM operations in software, exporting of G-code, preparation of mill, milling, and finally, sanding and finishing.*

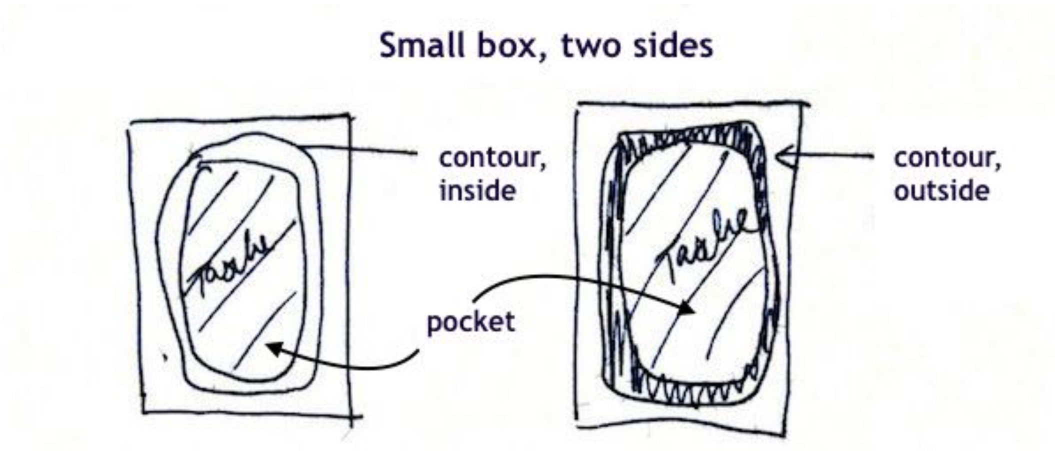

Fig. 3.4. Hand sketch of two separate box pieces for CNC milling.

Still, it presents the amount of consideration invested by the instructors and his colleagues in the development of the training. It was the first training during which someone spoke about the CAD/CAM pipeline from the beginning, and, yet, the course description only stated that it "would instruct in the basics for the operation of computer-supported machines."[121] It was the first time also someone considered explaining G-code as an essential feature for working with CNC (see Fig. 3.5). In many other instances, for example in 3D printing, the tool path is considered widely irrelevant as

[121] Retrieved from http://www.hei-muenchen.de/unserangebot/werkstaetten-und-kurse/hei-tec-werkstatt/einfuehrung-in-die-cnc-technik .

the CAM software application writes and debugs it automatically, meaning that access to a guidebook with all codes suffices for its understanding. This type of understanding contradicts Orr's argument that technical knowledge is a socially distributed resource that is stored and shared in an oral culture (1996). While some portions of the course were succinct, as it is challenging to train novices in all the CNC (milling)specificities within a few hours, this course with its multiple resources alleviated the complexity of CNC and CAD/CAM through aspects often assumed as redundant by others.

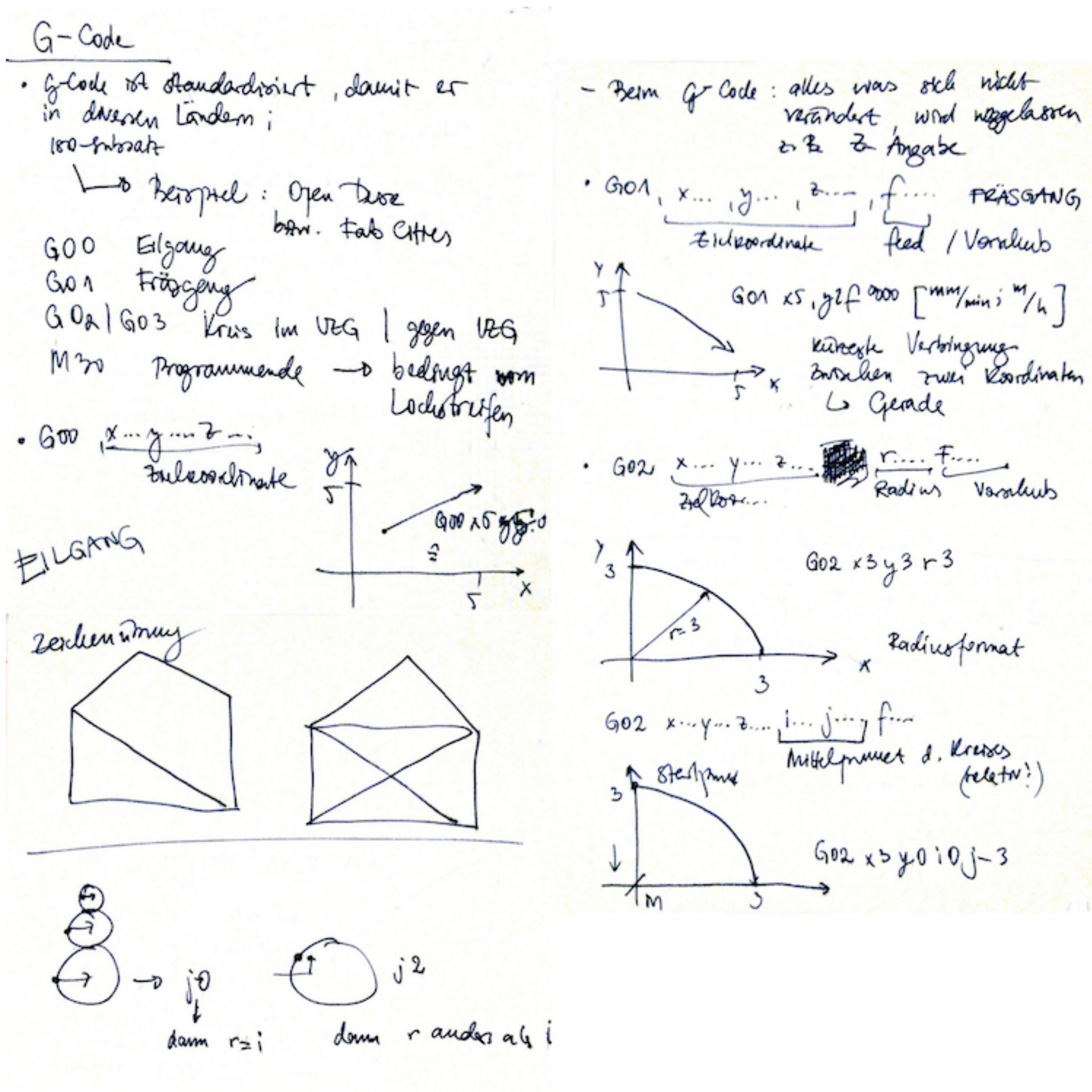

Fig. 3.5. Notes (in German) and sketches on G-code lines and geometrical exercises.

Digital Fabrication as Service

The final example of a probable disconnection between design and production is offering digital fabrication as service work. This recent addition of 3D printing and laser cutting (see Fig. 3.6) to a more extended set of outsourced services such as offset printing, screen-printing, but also casting or molding, however, is not my focus of interest. This form of service develops entirely autonomously from shared machine shops, although not necessarily having a different user group. Instead, what I am interested in is the different variations of service offered at shared machine shops and how service is interpreted as part of the DIY culture. In this final section, I will draw mostly on interviews and descriptions on websites.

Fig. 3.6. Flyer from a digital fabrication service collected by the author at the Maker Faire Berlin 2016.

The idea of service reappears across sites that also offer working space for rent, that is they operate as co-working spaces and innovation hubs at the same time. As a co-working type of space, their user group tends to have a specific professional position. The service offered mostly to members and customers is physical fabrication, as the technical manager at Make Works Toronto explains:

> *There's the two sides of it. I do it as a service. Members or people from outside can just say, "Here's my model, make this." Or even can say, "I want something like this," and talk with their hand. And then we can do the design for them. […] If people, even the people who are coming with products, [say], "In a month I'm gonna have to do one prototype," they just hand it off as a service. There's a fairly small price difference to it [own fabrication].*

Service adapts flexibly to the needs of customers and could even include CAD design. Speaking to one of the staff members during a tour of Vancouver's makerspace Maker Labs, she tells me that "[they] can make the project for you instead, if you're on a deadline or something" (2016). That could also include the designing. That way it just becomes more expensive. Members of the maker community do not equally appreciate this open attitude on providing digital fabrication services. However, like making and digital fabrication are becoming more and more embraced by corporations, institutions, and political agendas, the understanding of service crumbles away. Instead, it is depicted regarding "production" (Machines Room London), "product development" (MAKLab Glasgow), or simply "production of prototypes and small batches" (Makerspace Garching).

In the case of Machines Room, production usually means CNC milling commissions for the nearby located OpenDesk. Product development at MAKLab is a much more nuanced, as Dylan describes:

> By product development, you mean projects you do for someone?
>
> *Dylan: Yeah. We'll do kind of building projects and stuff like that, but product development can be very expensive very quickly for someone as well. A lot of the time someone coming off the street probably won't be wanting to spend about 16,000 to test out an object, and to do it properly it takes that amount of time, and that's our time. So we tend to advise them that these machines will be able to get you that far, and then to get it ready for manufacturing, this is what you need to do, because a lot of the time things you can make here you wouldn't be able to mass manufacture. [That] [s]omething can be done on a 3D printer, doesn't mean you can cast it in different ways. We explain them that and then hopefully guide their project that way and then when they join, we'll take them through the process of "Okay, you'll need to learn this for the first bit and try out these different methods, and then from there you'll know which way to go forward on it." (my emphasis)*

Their consultancy as a service rather aims at gaining members. I recall from my conversation with Dylan that because of their large shop window at MAKLab Charing Cross, located on a bustling intersection, many times people would walk in out of the interest provoked from "peeping through." Being unsure what the place represents reinforces the idea of consultancy as service. Carrying out digital fabrication as a service might contradict the idea of do-it-yourself. At the same instant, it is a formulation of returning production to urban areas. The same applies to having technicians in shared machine shops who execute commissioned works. They remain craftspeople but just working in a different environment than the usually expected one. Service appears as disrupting the proposed unity of design and manufacturing. Nevertheless, the distinct forms of service discussed here also show that this unity persists by being distributed across other individuals.

Conclusion: A Question of Control and Expertise

This chapter began with broader articulations of how making and digital fabrication present prospects to instantly materialize design within a technology or a process, and, thus to unite those to manufacturing as well. These propositions arrive from a long-standing division between design and manufacturing and a broader perception of design as an immaterial and conceptual practice. They further reintroduce the idea that design and its materialization by way of fabrication are executable by the same person. Seen as a paradigm shift in design, digital fabrication and making, however, propose associations of expected connections between design and production and, at the same time, probable disconnections. On one side, comprehensions of proximity on a personal, technological, procedural, and spatial level, as well as their translation into the sociopolitical and economic idea of urban manufacturing revival are framed as *expected connections*. On the other, the technical intricacies of learning the workflow of digital fabrication as presented in the various forms of CAD/CAM training at makerspaces, but also the increase of supply of digital fabrication service hint the *probable disconnections*. By demonstrating four distinct yet entwined subjects related to the epistemic practices of making and digital fabrication and their urban grounding, this chapter discussed how both design and production become transformed in a rather situated and nuanced way that calls for a "significant reorientation of design from the functionalist, rationalistic, and industrial traditions from which it emerged," as anthropologist Arturo Escobar reminds in his recently published book *Design for the Pluriverse: Radical Interdependence, Autonomy, and the Making of Worlds* (2017, p. x).

Design's principal aim for design theorist and wicked problems-originator Horst Rittel is the production of a plan. The plan's execution was left for others. However, as he asserts, designers worry about that concerned it could potentially reveal the plan's failures (Rittel, 1988). Considering the story of Wildgrid's demonstration from the beginning of this chapter, the burden of the failed plan execution perhaps reveals more about how design is still perceived nowadays. Plans and their visualizations remove the risk through the power of imagination. Material prototypes, models, and also final products ground design in reality and may reveal the shortcomings of the (design) plan. Still, controlling that means knowing how to fabricate. However, manufacturing as the execution of a design plan mostly happens outside the scope of design. As digital fabrication and making turn this potential problem into an advantage, to recite Downey (1998), other issues become opaque. While being able to materialize designs by controlling the process, as furniture designer and writer David Pye (1968) notes, in many instances those who execute the plan are omitted from recognition. Designers, makers, amateurs might materialize something, but their participation in human and non-human collectives means that this act is also delegated to the digital CAD and CAM applications, to the machine, to supportive tools such as the inconspicuous folding yardstick, or to all the online tutorial and files. Neglecting these guarantees control as some of the examples in this chapter have shown. For instance, failing to include how to design for CAM in training and in courses, or merely suggesting to bring a downloaded file, disunites design and production, even if not interpreted like that by many makers. At the same time, it shows how expertise is regarded as a matter of course. This taken-for-grantedness can promptly become the norm as the survey of forms of maker training suggests. However, norms based on a highly-ranked set of skills such as those that designers, architects, engineers acquire through education and work practice leave little potential for the other without access to such social technologies to unfold in a similar direction or become acknowledged.

Chapter 4.

Skilled Interactions: Reconfiguring Expertise by Making

> Perhaps, indeed, we might say expertise itself has been given notice to quit.
>
> —Caroline Bassett, 2013, p. 212

> In the accepted wisdom, we think of amateurs as people who dabble, who do things as a hobby rather than as a living, at weekends, in their spare time. They may be really good at something, 'experts' in their own right—at gardening, amateur dramatics, car mechanics—but it's still amusement, something *unimportant*. Professionals, by contrast, are those who apply themselves in *important*, instrumental ways. They're there to be listened to, taken seriously.
>
> —Andy Merrifield, 2017, p. 14 (original emphasis)

Cultures of making, hacking, and digital fabrication, along with the postindustrial manifestations of craft, DIY, repair, have been lauded as increasing 'everyone's' skills and expertise through hands-on practice in design and production. In the 2011 "Power of Making" exhibition, the Victoria & Albert Museum displayed a panoply of maker projects and objects to celebrate a variety of practices and skills—past and present, analog and digital, professional and amateur. Making, as designer and exhibition curator Daniel Charny writes, combines "two aspects of power"—technique and personal skills—to produce expertise (2011, p. 8). In fact, making gained popularity on account of the idea that one does not have to be an 'expert' to solder pins to an LED, develop a simple interactive installation with Arduino, 3D print the omnipresent Yoda head, or code a few lines. The presumed feasibility of these actions suggests a homogeneity behind all processes of making and digital fabrication.

Environments such as maker festivals, shared machine shops, educational programs in libraries and community centers, and online exchange formats reinvigorate this impression. Indeed, some individuals took the 'maker path' from novice to expert and have gained a considerable reputation in their communities.[122] While their expert status receives validation within these specific communities, it remains unacknowledged outside, where more strict mechanisms of expert credibility are in operation. On the contrary, the growing maker communities and cultures stipulate a level of complexity and proficiency to demarcate their activities from a perception of "serious leisure" (Maines, 2009; Stebbins, 1980). As a result, they become associated with a confirmative, gendered image of technical and scientific practices. The visible presence of a specific type of maker projects

[122] Prominent examples are Shenzhen maker Naomi Wu and Helen Steer, co-founder of Do It Kits, both challenging gender and technology stereotypes.

in *Make* magazine, festivals, and exhibitions such as, for example, robot constructions, drone competitions, or energy technologies reinforces the perceived scientific and technical character of expertise and required skills. Similar strategies have been observed in the editorial practices of Wikipedia which advertises itself as opening up knowledge production and enabling heterogeneity in participation yet its infrastructure is built upon a historically conservative—white and male—understanding of expertise, authority, and technical knowledge (Ford & Wajcman, 2017).[123]

Likewise, the glossy projects presented in *Make* magazine expose themselves as highly technical, requiring skilled experience with distinct knowledges—literacy in construction plans or instructions, proficiency in components and sourcing them, and ultimately capacity to rebuild the project on one's own. In her personal story of "becoming a maker," Egyptian architect Moushira Elamrawy recalls how her cherished radio broke during a long work trip between her city office and a construction site bringing her to search online for repair instructions. While the instructions provided many details "with neat pictures," she found them difficult to understand if unfamiliar with the parts and descriptions "in the first place" (2015). This initial experience shaped her successive journey in learning by making. Much of the maker tech appeared as "shiny and cute," she notes, but underneath the surface, it required a lot of technical skills and expertise to master it in a meaningful way. While maker cultures are based explicitly on non-expertise as a point of entry, the cultures themselves develop and maintain forms of expertise that enable their functioning. This informal notion of expertise finds expression in instruments like *Make* magazine or ready-to-use designs for fabrication in *Thingiverse*; it captures the method by which shared machine shops perform their pedagogies; and it characterizes the social structures around which forums and support groups are organized. These strategies institute local structures of expertise implicitly. In contrast, design practice, broadly defined, relies on expertise legitimized by a combination of formalized education, institutions, and professional experience.

This chapter, then, examines the reconfiguration of expertise in DIY maker and digital fabrication cultures. I argue that, rather than an explicit notion of expertise based around institutional validation, maker cultures cultivate implicit notions of expertise that are local, skill based, contingent and situated. In doing so, this chapter analyzes some of the following aspects and issues: Which type of expertise is at work in maker environments? What configures skill-based 'maker' expertise? How do other-than-technical and design skills operate in practice? To support my argument, on the one hand, I draw upon the scholarship in science and technology studies and the history and philosophy

[123] The Make Media franchise has its subdivision for this group of experts called 'Maker Pro.'

of technology to delineate relevant aspects on different forms of expertise (Collins & Evans, 2002; Haring, 2007; Orr, 1997), questions of legitimacy (Jasanoff, 2003; Rip, 2003), and skill acquisition (Franz, 2005; Orr, 1997) pertaining to technology and participatory practices. On the other, I examine the discussions on skills and expertise for making and design within human-computer interaction and design studies. Previous research on making has critically examined how less (technically) skilled novices access shared machine shops (Boussau, Tsandilas, Oehlberg, & Mackay, 2016; Hudson, Alcock, & Chilana, 2016), how their participation is encouraged (Rosner, 2012), and how knowledge is shared (Buechley & Perner-Wilson, 2012; Foster, 2017). A focus on design expertise for making and digital fabricate and the specific skills translated into these processes, however, remains marginal.

Building on this work, I build my analysis on web-based research material and fieldwork. The complementary web-based research draws on a Twitter exchange format for makers called #MakersHour, captured from June 2017 and January 2018 and subjected to semantic content analysis. The fieldwork, conducted between May 2016 and January 2018, combines two related methods. First, I draw on semi-structured interviews from the different makerspaces and fab labs I visited as well as on participant observation. Second, following an ethnomethodological and autoethnographic approach, I use field notes and vignettes from my personal experience of learning CNC milling. By combining these three analytic constituents, I attend to the ways different practitioners talk about the machines, technologies, and processes, as well as to the concepts, metaphors, and knowledges they call on, and how this becomes demonstrated in the performed practice. Lastly, looking at particular indications from this empirical data, I return to the idea of 'everyone's' empowerment with a discussion of the implicit gendering of technical skills.

Making Experts: Theoretical Background

In "Rise of the Expert Amateur," HCI researchers Stacey Kuznetsov and Eric Paulos (2010) present one of the first mixed-methods study of over 2000 individuals partaking in online DIY maker communities and practices. The attachment of the contrasting term 'amateur' to 'expert' positions individuals whose motivation to make things is noncommercial while differentiating from individualistic hobbyism and its discernible devaluation. Their motivation emanates from sociability as they find pleasure in sharing projects, experiences and skills, and learning new ones. Through dialogue and informal learning, offline environments such as shared machine shops and maker festivals are further lauded as shaping "sociable experts," rather than objects (Griffiths, 2013, p. 5).

Project assistance through peer-to-peer collaboration fosters skills "needed to respond to some of the complex issues we face in the world today" (ibid., p. 2). By empowering individuals and going more mainstream, maker cultures invoke "a new form of citizen engagement [.…] [by] turn[ing] passive consumers into active participants in state affairs and the market" (Lindtner et al., 2014, p. 4).

The question of decision-making in the public domain is reclaiming significance especially in the wake of wide-scale digitalization and data sharing. The projection of technological empowerment onto "citizens" resembles multiple theoretical frameworks in science and technology studies which broaden the perspectives on the relationship of science, technology, expertise, and citizenship. Inquiring the topic of technical and scientific decision-making, who gets involved in that (problem of extension), and whose opinion counts as expertise (problem of legitimacy), has brought forward conceptual articulations such as lay expertise (Epstein, 1996), citizen science (Ottinger, 2010), non-expert user interactions with technology (Eglash, Croissant, & Di Chiro, 2004; Oudshoorn & Pinch, 2003), or non-users and misusers (Söderberg, 2010; Wyatt, 2003). The problem of legitimacy frames many debates in STS: how to demarcate, to categorize, and to account for differentiated forms of expertise, who possesses the power to legitimate and bring different forms of expertise into essential decision-making apparatuses, and even what is expertise in the first place. Brian Wynne's pivotal study (1992) on the dismissal of Cumbrian sheep farmers' local knowledge, deemed trivial for the scientific examination of radioactive fallout, demonstrates the negative aspects of exclusion and demarcation of different forms of expertise. Likewise, the question of legitimacy of expertise in the context of making and digital fabrication bears similar substance.

"Making experts" by way of making and digital fabrication, however, complicates these perspectives on expertise precisely through the proclaimed fusion of long-lasting inadequate dichotomies—creative and technical, practical and theoretical, body and mind, material and digital, amateur (or lay) and professional, as well as female and male. In the following, I review scholarly contributions on expertise and skill. As such, this review is limited to the disciplinary fields and questions related to my research topic. I begin with an analysis of expertise concerning citizen empowerment through technological practice to discuss why these ideas become attached to begin with. I draw on the extensive STS scholarship on expertise with its nuanced definitions and case studies. By zooming into a granular level where expertise becomes defined more explicitly through skills, practice, and their embodiment, I move away from the position of the individual in society at large into the microscopic situations of specific practices, actions, and localities. The analytic research focus is on design expertise, skill acquisition in craft, design, and practice-based work, as well as recent research on newcomers and novices to making, digital fabrication, or design practice. Although these abstractions of expertise—the broader and the granular—relate to another and seem onerous to disentangle, many scholarly accounts treat them separately. Drawing on this theoretical review, I combine these abstractions of expertise (and skill) in my empirical examples to trouble the narrative of "making experts" through making and to foreground the invisible, unspoken, and ignored bones of contention.

Science and Technology's Impact on the Construction of Expertise

Sociologists of science Harry Collins and Robert Evans (2002) called for exploring 'Studies of Expertise and Experience' to approach the problems of extension and legitimacy in public decision-making on technical and scientific issues. Critical of the popularized term 'lay expert,' antithetically defined as someone lacking "professional qualifications or expert knowledge," they recommend that 'lay experts' should simply be referred to as 'experts' in public discourse, "[…] albeit their expertise has not been recognized by certification; crucially, they are not spread throughout the population, but found in small specialist groups" (p. 238). For them, these groups' special expertise which is based on experience and unrecognized by certification requires a new and accurate descriptor—"experience-based experts." However, experience in the context of science and technology is a contentious criterium to define expertise. Perceived as subjective, immeasurable, partially corporeal, and also feminine, experience, they clarify, is insufficient to define expertise, but it is "contributory" to it. Their proposal for a "normative theory of expertise" has come under careful examination by several STS scholars (Gorman, 2002; Jasanoff, 2003; Rip, 2003; Wynne, 2003) indicating that expertise and how it becomes framed remain debatable.

Arie Rip (2003) asks, for example, how the process of recognition of 'experience-based expertise' works. He notes that Collins and Evans leave this question and much else open. However, as he puts it, "[e]xpertise is always about something that is relevant for an audience: the courts, policy makers, decision makers more generally" (ibid., p. 420). Expertise, as Sheila Jasanoff challenges Collins and Evans's theoretical foundation of the model, is developed and placed across an individual's mental and physical skills, experience, but also their socio-political, cultural, and historical context (2003, p. 393). She reminds that a project of locating expertise in and for the public domain is also one of political theory which the call for a Third Wave cannot accomplish following such theoretical footing.

Further examples from the history of technology vindicate Jasanoff's argument. For Gabrielle Hecht and Michael Thad Allen (2001), for example, technical expertise conveys power emanating from privilege or institutional support: "Either way, expert knowledge and the artifacts it produced appeared hermetic" (pp. 11-12). Making and digital fabrication promise to unblackbox both expert knowledge and the artifacts produced by that. Nevertheless, many digital fabrication processes are persistently blackboxed as automation principles determine, for instance, how the 3D printing workflow is distributed into the closed systems of CAD software and machine models. As such these tend to disable modification, maintenance, and repair, therefore underlining once more the need for technical expertise. As digital media scholar Caroline Bassett observes, through the "miniaturization" of processes, functions, applications, and devices determined by ongoing computing developments much appears as 'accessible,' but the complex remainder turns indiscernible:

> 'Everybody' sees less 'technology' than they used to, and 'everybody' needs fewer technical skills to use 'skillfully' […]. Expertise might be said to have been reprivatized on the one hand even as it has been democratized on the other. Of what is left visible of computing, 'anyone can do it'; as for the rest, it is increasingly hidden in the cloud. (2013, p. 212)

Put differently, the interaction of technical knowledge, expertise, and operations for its legitimation influence the public understanding of expertise.

However, expertise, in general, and technical expertise, in particular, need not emerge out of institutional degrees, certificates, or professional regulations only. Studies on user adoption of technology by appropriation and everyday technology-entailing work practices (Haring, 2007; Orr, 1996; Takahashi, 2000) demonstrate ample validation of technical expertise unbound to traditional structures of power. Attentive to the different personal, socio-political, cultural, and historical contexts, these studies also foreground the fault line between skill and expertise. HAM radio operators in Kristen Haring's account (2007), for instance, possess sophisticated skills representing locally cultivated forms of expertise. While Haring's account, the specific user group of the long discontinued TRS-80 microcomputer (Lindsay, 2003), or microcomputer technicians in research (Zabusky, 1997) situate expertise in hands-on technical practice, studies of the early adopters of cars, in particular the Ford Model T indicate the absence of specific technical background and user experience (Corn, 2011; Franz, 2005; Kline and Pinch, 1996).

Early car owners relied on the translation of previous and partially unrelated experience to adjust their cars to their personal needs, or make ad-hoc road repairs. By applying solutions from handcraft or work knowledge to fix their cars, for instance, by patching car radiators with cooking ingredients (Corn, 2011), they demonstrated 'experience-based expertise.' Female car owners often used what is at hand—things like nail files—to take apart and reassemble an entire Ford Model T as they recalled seeing a technician doing something similar (Franz, 2005). Such accounts suggest that newly introduced technologies predispose for temporary relocation of technical expertise outside its social and historical norms. Necessity also impelled North American farmers in the 1920s to 1940s to tinker and convert automobiles into farming machinery to meet agricultural, and household needs (Kline & Pinch, 1996). Drawing upon experience and skill with household or rural technology—machine-specific, interactional, embodied, interpersonal—these different groups might not have qualified as technical experts of automobile technology according to public standards, but within their specific social context they qualified.

However, demonstration of expertise is also embedded and entrenched in hacker and maker cultures as well as citizen science communities through the practice of public demonstrations and witnessing.[124] Whereas the two noblemen were not located on the fringes of societal expectations on whom and what counts as a public expert, hacker groups such as the Chaos Computer Club (CCC) community require the development of a complex socio-technical and media apparatus to gain the needed expert legitimacy by society and legislation (Kubitschko, 2015). By interlocking their activities with broader ones such as public consultancy, political activism, and public relations, which expresses the heterogeneity of practices, skills, and interests of the organization, the CCC gets acknowledged as an expert community. Maker cultures and DIY-related activities also rely on similar public demonstration of skill and expertise to gain acknowledgment and credibility.

Skill Is to Craft What Expertise Is to Design

Experience as the previous section illustrated is a contested standard to account for expertise. Nominal notions, in particular of professional expertise, downplay the central role of experience. Studies on expertise and skills in design have argued that the central research focus has been on design students or less-experienced designers, whereas experienced and professional practitioners have been explored little (Cross & Cross, 1998; Lawson, 2004). In their study, design researchers Anita and Nigel Cross contend that the distinguishing mark of expert designers is their ability to start anything from scratch instead of build upon prior situational knowledge. Their position stands in stark contrast to the inference from a series of protocol studies on student designers noting that expert designers take prior knowledge such as "solution models" into account (Cross, Christiaans, & Doorst, 1994, p. 40), a

[124] This epistemological method dates back to the 17th century and the dispute between Robert Boyle and Thomas Hobbes on air-pump experiments (Shapin & Schaffer, 1985).

position Cross later restates (2004). There he notes that the accumulation of experience is essential for the transformation to an expert designer. Novice designers, on the other hand, cannot yet determine which procedure would lead to task completion, as a result relying on trial-and-error processes (Popovic, 2004). Expert designers, I suggest, rely on accumulative, domain-specific experience, but the subtle difference to other levels of expertise in design is the ability to determine whether to extrapolate this experience or take an utterly unknown path. Besides, counter to some of these theoretical positions, I argue that studies on design students tend to proliferate the experiences and skills of the "highly skilled ones" by being framed in a specific socio-technical context.

While the design scholarship's broader focus is on expertise, craft research concentrates on the notion of skill and its mastery. This distinction, in particular, relates to the increased alignment with scientific methods and synthesis of design in the immediate postwar period. It also persists in present-day design variants, for instance, human-centered design, service design, or design thinking, for which machines and technology present no threat to physical practice. The likelihood of a skill being displaced by the introduction of a new machine or technology particularly has been discussed within the topics of deskilling (Noble, 1984; Winner, 1977) and upskilling (Zuboff, 1988). Reviewing this scholarship, sociologist of work Steven Vallas (1990) discusses the meaning of the concept of skill to understand the inconsistencies behind many theoretical discussions. He notes that despite the relevance of skill for work analysis, there is little agreement on its definite meaning, and how to measure it. The absence of a fixed agreement about skill, in a way, recalls woodworker David Pye's preference for the term 'workmanship' over the term skill. In his acclaimed book *The Nature and Art of Workmanship*, Pye declared that skill "does not assist useful thought because it means something different in each different kind of work" (1968, p. 23). It also explains why the definition of skill in many of Vallas' reviewed studies derives from the relationship to the technology being introduced. Skill in the context of technology therefore gets grouped into the two clusters of upskilling and deskilling. However, as he argues, "far more complex and contradictory processes" happen behind this dichotomy that require more nuanced theories such as a social construction of skill or tacit and embodied knowledge.

A socially and historically contextualized account on skill and skilled practice is provided in Trevor Marchand's ethnographical research on craft and craftspeople. The social anthropologist has studied a variety of traditional craft communities from minaret builders in Yemen to woodworking apprentices in London's East. His work emphasizes questions of the function of apprenticeship as a social practice, the place of social knowledge, as well as the role of the body in the process of learning skills. His multi-sited and multi-cultural studies manifest "that the body is not universal or ahistorical: but instead the 'knowing body' is socialised and gendered and it continues to learn, strategise and change over time" (2008, p. 256). The bodies and their skills or vice versa respond to ongoing social, physical, and technical transformations of the environment. As Ingold puts it, "skill [...] is constantly challenged by unfamiliar situations" (2018, p. 161). Marchand's study of woodworking apprentices demonstrates that the conceptions of skill training in England have adapted to the nation's political and economic conditions, for example, by increasing theoretical knowledge through textbooks and lectures. Despite this process of codification of craft knowledge, Marchand reminds us that "any practitioner knows that the most efficient understanding and acquisition of craft skills comes from the animated body in practice" (ibid., p. 260).

Novices in Making

Making involves skill-based expertise despite reaffirming that skills might not be a pre-requisite for participation. So how are novices becoming aware of their ignorance of specific making skills? What strategies are they applying for the acquisition of those? In the following, I discuss through prior research on makers' experiences with technology the prominent methods of skill learning. Skill learning, following philosopher Michael Polanyi (1969) and writer David Pye (1964; 1968), requires social and material interaction. Being a popular source for learning making, DIY, or craft, online videos and video tutorials provide a technological alternative to the socio-material interaction. However, because expert skills are distinguished in their profound embodiment, these videos present an insufficient alternative to articulate craft knowledge to novices (Torrey, Churchill, & McDonald, 2009). The embodiment of skills makes it difficult to communicate this form of knowledge via a mediated format. However, some mediated format to support the learning of new skills usually accompanies even the social interaction-based learning.

Studying the experience of newcomers to 3D printing who approach the technology in walk-up centers such as libraries or community centres, Hudson et al. (2016) observe that novice users turn to platforms such as Thingiverse where they can find a variety of pre-made 3D designs. Often advice to use a platform and its tutorials comes from the workshop staff, here called "operators" following Julian Orr's work on photocopier technicians (1996). However, as they argue these platforms tend to highlight complex prints by experts ("not amenable for learning") which creates false expectations onto 3D printing and 3D modeling (2016, p. 390). Moreover, platform designs are rarely made for customization. When possible, users require additional and more complex tools (e.g., specific modeling tool, openCAD). This, however, does not account for the "interdependencies within the 3D printing workflow" (ibid., 385), thus creating a dependency on the expertise of the so-called "operators." At the same time, these "operators" only learn the necessary technical skills to handle the fundamental tasks of 3D printing, what I call *operational expertise,* but for complex issues they "defer to other experts in their networks with more expertise to address users' issues" (p. 387).

As this study reveals, most CAD tools used for 3D printing but also digital fabrication in general entail a certain complexity which resembles Bassett's argument about "miniaturization" (2013) foreclosing that by letting the surface appear as effortless. Other scholars have also explored the professional context of development of CAD tools, and why novice users including HCI design students by finding them too complex invest little effort in learning those (Bousseau et al., 2016). Within the context digital fabrication practices for design and architecture education, computational design researcher Dina El-Zanfaly (2015) argues that the partial automation in digital fabrication constricts embodied interaction. Embodied interaction for her describes the ability to integrate digital fabrication into the design process. However, formalizing the digital fabrication training in a scientific way as architectural and engineering pedagogy has been undertaking, trains students to adapt their knowledge and produce to the capabilities and limitations of the technologies. This process she contends teaches only in the machine functionalities and operations. Besides, "[t]his kind of instruction-based learning to make does not allow the learner to transfer what has been learned to another problem or project. A novice maker might learn to make a curved surface on a 3D printer, but s/he may not realize that s/he can also make this surface with a laser cutter" (ibid., p. 10).

The question of transfer of general or personal skill and knowledge to the technical practice of "crafting technology" has also been the focus of Buechley and Perner-Wilson's study on the relationship between craft and electronics through an early survey of a group of makers (2012). Counter to El-Zanfaly's argument that novices cannot translate other skills and knowledge into something distinct, their study shows that people persistently draw upon other existing forms of interest and expertise in carving, sewing, or painting to tackle the problems they encounter in programming electronics.

Hashtag MakersHour: Listening to Conversations on Skill and Expertise from the Distance

Drawing on social media data in this section, I review what self-described makers consider as skill and expertise related to their practices but also the methods, instruments, and technologies they draw upon to obtain or improve skills. The following data originates from a web-based conversation on Twitter called #MakersHour launched in June 2017 by the UK-based Guild of Makers.[125] The #MakersHour happens every Wednesday evening from eight to nine pm (UK time). Within this hour, by using the hashtag MakersHour Twitter users identifying as makers can join a moderated conversation based on five to seven themed questions. Conversations are chaired by a member of the Guild or a follower expressing interest in the role. Questions are regularly announced by a photo tweet in advance (see Fig. 4.1). Additionally, followers unable to join the live conversation get the opportunity to re-experience them online on Storify.

I discovered #MakersHour into its second month through a maker on Twitter. Initially, I followed the conversations randomly until one evening when I discovered how enthusiastically people discussed the questions. Looking more carefully into the questions, the answer, and the plurality of making beyond the usual tech-proficient narrative, I revisited the previous #MakersHours back to its launch. By using this semi-structured, open form of conversation with multiple interlocutors as research data, I gather less determined and guided results compared to conducting an online survey on the topic. Besides, in several instances answers led to transitional, new questions. The followers also react to one and another creating a conversation rather than survey answers. Although the conversation is moderated, it serves to organize the format, so people could connect answers to specific questions.[126] Another appealing aspect is its discernible diversity among its followers when corresponding to gender and practiced maker skills. Knitters and crocheters are on par with computer programmers or metal welders. Most of them were thrilled to be in conversation with strangers who seemed to appreciate time and effort that other people invest in self-initiated activities.

I collected these questions and answers in a timeframe between its launch in June 2017 and end of January 2018 (35 weeks). This entailed a weekly live reading or a post-factual re-reading of the conversations when I was unable to join when it happened. Instead of saving and coding every possible question and answer, I used the pre-announced questions to determine whether a weekly theme relates to my research topic. The results (60 questions) were coded and subjected to content analysis. In this section, I discuss a sample of 14 questions and 320 answers relating to the topics of

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125 The Guild of Makers is a membership organization aiming to provide virtual and face-to-face networking and other forms of support for people interested in making/DIY who intend some professionalization of their practice. It hosts a range of activities along the weekly #MakersHour on Twitter such as talks, workshops, or a Slack channel. Retrieved from https://www.guildofmakers.org/.

126 When followers missed to include the specific references, for example, for the first question the moderator uses the abbreviation Q1. An answer to that would be coded as A1. If followers missed to include the matching handle, the moderator made sure to retweet accordingly.

skill, expertise, and what forms them. Based on the coding, I have structured the analytical discussion in four groups: learning of skills and their origin, role of non-technical skills for making, instruments for skill acquisition and demonstration, and, finally, skill aspirations. These groups, however, are entwined.

Fig. 4.1. #MakersHour announcing the questions two days in advance. Source: https://twitter.com/GuildOfMakers

Twice followers were asked to assess the "roots" of their skills as either innate or nurtured in relationships. The discussion around nurturing skills reveals more nuanced replies. In many cases, a parent, usually the father, was an engineer and that motivated the skill-building process. While this reproduces a typical image of the male garage tinkerer, especially if expressed by male participants, mostly female participants describe a broader range of skills and family relations. One of them stated that "mum and dad definitely taught me a [lot]. Between them they can do: sewing, embroidery, dyeing, spinning, weaving, leatherwork, […] [m]etalwork, welding, blacksmithing, engineering, electronics, wheelwrighting, woodwork, bricklaying, pyrotechnics, and more" (Erin Fox, 2 August 2017).[127]

[127] Names and Twitter identities have been changed. The @ symbol identifies a Twitter user name. The # identifies a

Another highlights their mother's cooking along with grandfather's woodworking and uncle's programming. These questions illustrate that while popular accounts of making tend to valorize high-tech innovation skills as core inspiration, makers also connect their experiences in a more subtle way. For school-based education related to fabrication skills, most credit wood and metal working or technical drawing. However, these subjects and handiwork have nearly disappeared from school curricula. Where such education is unavailable, maker skills are likely to be obtained through peer learning or various media such as instruction books to YouTube video tutorials. Makerspace workshops and training sessions are such form of peer learning. Learning new skills also tends to happen on the go and if needed, as several #MakersHour followers explain, while having a goal or project in prospect allows to connect better to the skills being acquired.

A disputed topic, however, is the role of 'soft skills' defined in one question as public speaking or negotiating. Such framing of 'soft skills' stirs the conversation in a specific direction without much room for interpretations. Nevertheless, many participants agree that 'soft skills' are an essential asset for making when this happens in a community-contributory context. As one of them writes, "If you want to make in your shed: no. If you want to give to your community: yes!" (Kate McDonald, 10 January 2018). Art practices and art education were also discussed as a transferable skill for making. Art for many is considered as interesting but abstract. For one follower, however, the problem of not acknowledging art is brought forth by a "broken and disjointed" educational model which separates instead of creates synergies between the distinct disciplines—a problem often treated uncritically by establishing synthetic educational models such as STEAM, itself a derivative of STEM.

As the theoretical discussion on skill-enabling tools for making revealed above, maker education is to a degree made possible through the many decentralized Internet technologies (social media, blogs, online peer-to-peer networks). "The Internet seems to be the enabler for most of our skills[,]" posts the Guild of Makers. However, as one conversation reveals, media tools and instruments are just one of many resources supporting skill acquisition. They serve primarily as inspiration, but for instance, the specific pacing of video instructions makes them challenging to synchronize with one's own pace of learning and making. One follower dislikes "the slow progress and terrible indexing in videos" (Pen Michael, 26 July 2017). Although blogs and videos present a substantial reference for learning skills, when it comes to physical processes such as CNC milling virtual sources become insufficient. "For machining[,] I went back to college[,]" explains another follower (Terry Jackson, 26 July 2017). Many

searchable theme across the Twitter system.

of the regular conversation participants highlight the role of access to physical spaces and events, from local makerspaces and coding jams to museums and galleries, for attaining new skills.

Relating skills to specific technologies and machines, followers in one question were asked, if funding was not an issue, what kind of machine would they want to possess. Three aspects stand out in the answers: time for learning, larger space to work in, and CNC mills. There is an interesting correlation between these. If one wants to learn CNC milling, most likely one would need a lot of time, and also more workshop space if the machines exceed the desktop size. As for a specific skill that people desired to achieve and if other #MakersHour community could contribute with their expertise in that, very few express interests in electronics and programming that many others could provide help. Instead, a majority desires to learn more artisanal or manufacturing skills such as welding, metal and woodworking, blacksmithing, cheese making, and, in unison, CAD, CAM, and CNC milling. Many of them are difficult to codify in online media and require physical access to the specific tools, technologies, workshops, as well as experienced craftspeople and technicians. Yet some of these requirements are not always met by shared machine shops as I later illustrate with my training in CNC milling and the CAD/CAM process.

Zooming in: Making Maker Skills and Expertise

> *If you come to a makerspace, they'll teach you how to make [on] the machines. You can learn it just as much as anyone else can learn it.*
>
> —Matt Gilbert, Animaro / Machines Room, London, 2018

The previous examples from the #MakersHour conversation attest to empirical research on maker cultures and digital fabrication (Buechley & Perner-Wilson, 2012; Davies, 2017; Foster, 2017) by uncovering an interaction between 'curiosity' about these technologies and places, on one side, and the perception of skill and expertise rooted in them, on the other. In particular, the portrayal of DIY electronics, 3D printing, and laser cutting in contemporary media fosters their status as what social anthropologist Alfred Gell has termed as a "technology of enchantment" (1992).[128] As such, uncovering their internal workings and intricacies endangers the potential of their spectacle and their

[128] First, in his famous essay (1992) and later in his book *Art and Agency* (1998), Alfred Gell provocatively proposed an anthropological theory of art that took art as a specific form of technology. He argues that technology appears as enchanting because it has been constructed in a nearly mystical process for those outside of its original social circle, and as a result cast its spell on individuals.

authorities.[129] Likewise, many makers show awareness of their ignorance (of experience, knowledge, and skill) in these technologies and practices, as well as of the manifold strategies attached to their acquisition. As community manager Mikael from Copenhagen's Underbroen reveals, "[p]eople coming from the street are most interested in the laser cutter because it seems easier[,] [a]nd then people who actually know already a bit about this are more interested in the CNC [mill]" (2017).[130] Makers seemingly bring in an understanding of the complexity of these machines and processes in relation to their skills or absence of them. While the previous section presented how distant (to me) makers discern maker-bound skill and expertise, here drawing on interviews with staff members and core members from my field sites, I want to zoom in on the provision for makers by the spaces themselves.

Implicit from the discussion of training typologies in the previous chapter, access to these technologies and practices involves some form of guidance afforded through teaching and training for numerous reasons. The understanding of what training should provide in terms of knowledge and skill and how involving that might be, however, varies across spaces and people. Its interpretation, in a way, corresponds to the different implicit meanings of DIY: from an autodidactic stance of "just do it" (Dahm, 2017) to the careful and supportive co-learning and co-creation with and from others. Besides that, personal or collective attitudes of the staff involved in shared machine shops connect to the governance and funding structures of these places. They also point to the tensions about skill and expertise within these communities. Smaller spaces mostly provide their services owing to volunteer work by both members and organizers. It means that having fewer members would allow for careful dedication of time to teaching and supporting others. At the same time, the situation might be the opposite. Expansion of membership without remuneration of this labor keeps the time for training and social skill interaction to a bare minimum. Usually, that includes inducting into the safe operation of a specific machine or technology, or just showing where to retrieve operational information such as a manual.

At Toronto's InterAccess, self-described as production studio, educational facility, and gallery, where the "studio space facilitates the circulation of skills and techniques required to produce the work [they] exhibit in [the] gallery space", the studio technician explains that his responsibility is to "give people some basic tool training […] [,] a safe overview of how to use a piece of equipment

129 The miniaturization of digital fabrication technologies, thus making them portable, allows for a "pasteurization" (Latour, 1984) of the technological practices behind them. At the same time, as Latour demonstrates, the action of bringing the laboratory with its tools to the outsiders works to cement its expertise.

130 Mikael's account also resembles Herbert and Stuart Dreyfus's model of expertise (1986). If learning to work and fabricate with a 3D printer or laser cutter equals being an advanced beginner and requires some competence, the CNC mill amounts to proficiency and expertise.

[…][,] to make sure they don't hurt themselves, or damage the machine" (Z. Miller, personal communication, June 8, 2016). However, if visitors of the weekly open studio hours and regular members want to learn more, that is on them. That as he adds "takes practice and time," or capital—"if they want any in-depth knowledge, they'll have to take a workshop for it" (ibid.). This position on DIY learning and the expectation of what that entails is not unique to this place. I call this formula *operational expertise*, or as Ross at Machines Room defines it: "That just teaches you what you can do with it and how it works" (R. Andrews, personal communication, December 1st, 2016). That means, it provides enough self-assurance by showing basic technical functions and components by the experts, usually, the staff or volunteers, while reinforcing the conditions to return for a detailed and priced special training session. Nearly all in-between models that I have observed in different makerspaces establish this practice in one form or another.

At Happylab in Vienna, also a small franchise with locations in Berlin and Salzburg, the formula works by way of simplification of the digital fabrication workflow for each machine. That, however, is not contingent upon machine work only as their fab lab manager explains. Instead, it creates a system involving personal support and the deliberate decision to side with comparatively accessible machines and software. "So that people have easy access," he clarifies (Jung, 2016). The downside of that decision is a limitation in the functionality of the software but sufficient for the 'average' user to work on their own. Concurrently, avoiding to turn away advanced or even expert users because of this limitation requires a modular solution for software compatibility. Often shared machine shops achieve that by choosing, for instance, a CAM software that supports the broadest possible range of CAD-file formats. But such system revolving around technological accessibility considers another less perceptible aspect, namely the logistics of running a shared machine shop. While Happylab has been successful in attracting a high number of members and users, in part due to their affordable fee model, their locations have maintained an unchanging number of technical staff. Besides, support by the technicians as employees is limited to regular business hours. Yet the space, as many others, offers and actively promotes full-time, 24/7 access. Therefore, employing technologies that are easy to comprehend allows for a different interpretation as well. The formula for user-friendliness converts into one for logistical obstacles—numerous users, inexpensive support, and the possibility of time expansion. However, the revised formula also leaves it to members to work out machine issues on their own if neither technicians nor other members are nearby (Boeva & Foster, 2016).

A token of DIY and maker cultures is nevertheless learning from others, and that even applies to advanced makers with professional degrees. Most scenarios involve recognition of one's ignorance as part of a project that requires learning the respective creative or technical skill. For Machines Room-resident Ross, the process of translating the 'antique' blueprint of the punt into a full-scale wooden boat, depended on other members' advice, in particular, when he got stuck with the intricacies of computer-aided design like "how to do that bend and that shape" (2016). Mikael who is continuously around in Underbroen, but who also as I noted in *Chapter 2*, arrived in this hybrid techno-creative culture from a mixed background in humanities and business, reveals that this distributed social expertise assists his daily job there:

> *I, at least, learn a lot from the others. When I need to know anything, and I want to know anything, I can always just ask, and then ninety percent of the time people have the time to actually help me out. […] But of course also with competencies and helping out, troubleshooting on the machines, and so forth […].* (Christensen, 2017)

Another form of learning from others emanates from the pedagogies in traditional craft apprenticeship but also in cooking or nursing—that is learning through observation. Whereas the 'learning from others'–attitude that I have observed and also practiced myself situates within a problem-solving context, observation embraces an encounter with the unforeseen. This form, however, implies a model of apprenticeship with prolonged duration and regular attendance of such spatial infrastructures. Niki's somewhat loose-structured internship at Machines Room designated time for her project-based learning, as well as spontaneous and unplanned moments of idleness.[131] These moments represent unfamiliar opportunities to thicken the layers of personal skill and expertise as Niki reflects upon:

> *[F]or me, being here means I'm observing stuff and it's like, you have many hours of practice, actually. When you are going to make your own thing, it's easier because you already have the experience of ... You know? And it's easier to see people doing mistakes because then you [think], "Oh, I'm not going to do that because I remember that this guy had done that and he broke something. […] That's pretty important.* (Nefeli, 2018)

In other words, time along with capital in their multiple manifestations make up critical criteria for developing skills and expertise in these practices. On the one side, one needs time to learn a skill well, thus to gain expertise, but also to distance from that through reflection.[132] On the other, working

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[131] I recall my time as an undergraduate intern at an audiovisual production studio. During production peaks around term deadlines, people would require our support simultaneously in several projects. At the same time, when projects and technology worked, in a way there was no socio-technical "breakdown" (Jackson, 2014), I recall day-long idleness and enjoying to observe others working and learning something from that.

[132] Coined as the term "reflection-in-action," Donald Schön proposes that reflective practice is a dialect process in which thought is integrally linked with action (1989).

on a tight schedule prompts ad-hoc practices and remedies that might not lead to the desired results if more time and experience were at one's disposal. When talking with Ross about the punt-building process, I asked him to estimate his time investment in the entire process from learning how to translate the hand-drawn blueprints into a 3D model to finally assembling the CNC-milled boat parts. He approximated a total of two weeks for the design process and another week for milling and making. At the moment, I was amazed as it seemed a short time. His clarification, however, that learning to design took "over a couple of months in the evenings" (2016), and my similar experience of designing and building a modular shelf, reminds that access to these technologies and spaces is not equal to skillfully interacting with them. Skill is often taken for granted remarks craft and design scholar Glenn Adamson (2007, p. 69). In hindsight, Ross reflected about his undertaking as a novice maker that "if [he] had sat down with somebody and tried to do it with somebody who had more experience, it would have been a much quicker process" (2016).

The conversion from knowing about to knowing how points to the question of transferability of skills and expertise. The educational background, and thus the practical experience from architecture school that some of the resident makers such as Matt Gilbert and Niki could draw on, configures not only how they approach problems with things they fabricate, but also how they approach new skills and learn those. Although being less experienced in design and design-focused fabrication according to his description, Ross nonetheless converted his knowing about design into a knowing how to accomplish the design process by taking the day-long CNC machine training as a starting point:

> *From that I was able to go, "Okay, I could build that punt on this machine," and also to work out what made sense to build on the machine and what made sense to build by hand. So, it was useful in that sense.* (Andrews, 2016)

What also helped him, however, is having a project in mind:

> *I was really keen to learn the CNC cutter because I think it's a very useful tool, and I'm bad at learning things unless I'm doing something real. I can't make up a project for no reason at all. That seems [like] a lot of a waste. So, I needed a real project.* (Andrews, 2016)

That the team of Machines Room was planning to participate in a raft race between several of London's shared machine shops, and thus in need of a "floating contraption," that they also had a CNC mill, and that Ross was a knowledgeable member of the local housing boat community who also expressed interest in familiarizing with the CNC mill, make for a serendipitous explanation. Situating this interest in a tangible context assists in two ways. First, it gives the skill learning and the potential expertise a certain structure. The ambition, however, is not to control chance, the practice maintains a sense of opportunity. Second, such context diminishes the unfavorable "enchantment" of CNC machines as complex and high-risk by breaking down the experience with them in single entities—as also practiced in training sessions. As Ross puts it:

> *So, they needed some kind of floating contraption made and I wanted to learn the CNC machine and a bit of 3D modeling and work out how you could get old school plans into modern files. […] I just took these old punt plans and just messed around with it in SketchUp to build a 3D model, and then flattened that all out and worked it out on the CNC machine, what bits I could do and what bits I couldn't do, which bits would be useful to do on the CNC and which bits I needed to do by hand, and then put it together."* (Andrews, 2016)

My point is not that by having a project in mind and breaking it down into components, the CNC mill becomes a machine that can be approached without concern. Instead, that specialized technology such as CNC milling, as most of the technical managers in my field sites reaffirm, tends to be used by specific people either with some experience with it or with the apparent motivation determined by the project (C. Stevens, personal communication, October 13, 2016). Nobody learns CNC as a form of 'serious leisure,' as Fab Lab Berlin's manager Chris responds:[133]

> *[…] every time it's just, it's been someone who has a project in mind […] and then they either already know they need to use a CNC machine or they come here and [say] "I want to build this thing," and I would have said, "Okay, the CNC machine is the tool you need to use to build that. You can't do that with a laser cutter." Then they go through the process of learning it to build up projects. But I don't think anyone's coming in just to learn how to use a CNC machine just for fun.* (Stevens, 2016)

On that account, I disagree to a certain extent with Ross and Chris's positions that learning and working with a CNC mill is more effective if project-motivated. My experience in learning CNC milling did not follow a particular maker fabrication project but an inherent interest in fabrication machines.[134] It also followed my intention to understand how these practices and machines, or technology in general, become gendered. As such, that entails grasping first the core functionalities

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133 Admittedly, his answer seems evident but if 3D printing evokes a notion of entertainment with the myriad of toy-like objects, then why not CNC milling? For the untrained eye of the nonprofessional, the "lay designer" (Campbell, 2017), or "expert amateur" (Kuznetsov & Paulos, 2010), the immediate material aesthetics of a Van Bo Le-Mentzel's 24 Euro chair, a Sedia Uno by the refugee collective Cucula, or Jose Pacheco's Slim chair designed for the digital fabrication platform Opendesk, are not discerning the tools and technologies involved in designing and fabricating those. They are all made out of light plywood, and they all take their impulse from Enzo Mari's *Autoprogettazione*. Only a closer look, of the price-tag as well, hints that the first two follow a more 'hammered' approach, while the latter one demands a CNC mill, a makerspace, a contractor, and the respective expertise in building furniture.
134 It might be argued that the dissertation project itself was what I was 'fabricating.'

of the technology by embracing their availability. In a way, my attitude aligns with many of the shared machine shop's interns I met. They arrive at these environments with some preconceptions of the technologies and the skills required for their mastery, perhaps with ideas for projects, but then the chance might lead them in an unexpected direction. Again, not to claim that CNC is straightforward but being around it facilitates comprehension, as one of Underbroen's interns articulates:

> *The thing about CNC machines at least for me it's a very complicated concept, especially if you haven't worked with it before. But having it available and being here and doing the hands-on, yeah, so for me it is to grasp the concepts of the G-code and CNC milling. It makes much more sense when you actually get to do it [.]* (In: Christensen, 2017)

Endless access also enables shared machine shop technicians to build up confidence in training in the machine. This is not a given concerning the skill and expertise involved. Machines Room, as the technical manager told me, took several months before they could provide access to members to the ShopBot. This was primarily the case so that Sam could figure out how to train members and what theory and practice to include. Not having any experience with CNC milling himself, the training he provides now draws on this initial learning process and the day-to-day practice as a contractor for Opendesk. Nonetheless, the training structure as a process is never finished or sufficient, as he reveals: "I play with it a bit, it's just more evolved, it's just more to remember" (S. Fuller, personal communication, January 16, 2018). At the same time, Sam's and Machines Room's experience, although probably resembling the situations at most shared machine shops, strike me as contrasting what commercial and industrial versions offer. I took one of my training sessions in precisely one of these. Catering to industrial clients but simultaneously offering maker services to "everybody," their specialized personnel depends on professional technicians or retired engineers with an equivalent work practice and expertise to their clients. Such orientation is designed to delineate professional from nonprofessional, not to transgress them as broadly proclaimed.

The question of demarcation points to the debates of legitimate forms of expertise. The examples I bring here into play emphasize that expertise in making constitutes a local and limited form which in many ways corresponds to other specialized knowledges and expertise. As such, they validate a specific knowledge for a particular context. The scenario that MAKLabs' studio mentor Dylan describes presents an intelligible account of acknowledged maker expertise:

I think with enough experimentation, a hobbyist can definitely become an expert in a field of that because it can be so narrow, and if he's so interested in getting that far to do usually just what they want to do, at that point, they can become consultants to professionals who are looking to either industrialize or capitalize in something that their expertise has developed, so things like CNC furniture, to be able to create designs that someone could modify like Opendesk. If someone's making enough CNC furniture, eventually they'll have enough expertise to talk to people like Opendesk and be able to join teams. Definitely with things like 3D printing as well. (Rand, 2017)

In this particular case, expertise might be the wrong term, instead what the maker of his example "capitalizes" on is their skill in CNC fabrication of furniture. But to capitalize on it, it requires a system where it can be reckoned as legitimate expertise. This, however, as Dylan suggests proves difficult to perform owing to what he calls a "grey area" between recognized expertise and an individual's actual expertise.

"CNC Milling for Dummies": A Personal Account

> My particular take on this [i.e. intergenerational and trans-disciplinary exchange] is that whenever one enters a fablab, there is already a spatial organization and a number of expectations about what is going to happen.
>
> —Felipe Fonseca, 2017

Late in my fieldwork, I decided to embrace the opportunity and learn what many consider the most complex digital fabrication technology in non-industrial shared machine shops—CNC milling. CNC milling with wood on a ShopBot frequently occurred in my interlocutors' representations.[135] Yet I rarely caught CNC milling in action, and even less so through my action. From the outset of my dissertation, learning and accomplishing projects with Arduino and Raspberry Pi as well as tapping into 3D printing seemed more like a natural fit for me. Having a background in media and information design engineering and a degree in media theory, my work had always shifted around intangible things, media representations, virtual worlds, and the like. But as much as electronics and 3D printing shape and popularize the development of digital fabrication, I find the complexity behind CNC milling with the possibilities it enacts an unequaled instance of what digital fabrication promises—connect design to manufacturing in an immediate ramification. I took this impression as my point of departure for learning about the machines and the related CAD/CAM process. In this section, I revise my

[135] Listed in the Fab Foundation inventory for fab labs, ShopBots are often the first choice for a CNC mill in makerspaces and fab labs. As such the brand constitutes what Callon (1986) calls an "obligatory passage point" for potential makers, makerspace owners, or also other commercial manufacturers regarding machine options.

experience from participating in one demonstration and three training sessions on CNC milling over the course of six weeks. These training sessions are structured around the social and technical infrastructure of each specific shared machine shop.

The sessions gradually enabled my skill acquisition similarly to the "five-stages-model" of Hubert Dreyfus and Stuart Dreyfus (1986). Their model introduced during the heyday of AI expert systems breaks down the scale of skill development into five intermediary steps: from *novice* (1), over being able to cope with real situations as an *advanced beginner* (2), through the adoption of a hierarchical procedure of decision-making expressed as *competence* (3), and applying intuition in the form of *proficiency* (4), to ultimately an *expert* (5). My experience in CNC milling, however, could not pass as accomplishing the five-stage model since Dreyfus and Dreyfus argue that purely procedural knowledge in insufficient for expert intuition and technical skills also require experience-based learning through some form of apprenticeship. Instead, I draw upon the model to situate how the complexity determined by the machine (CNC mill) configures an individual's level of skill and expertise through practice.[136] The assemblage of embodied, technical, and material knowledge revealed in the simultaneous ability to design a manufacturable model, to set up and operate the mill, and to determine the material fitting—these are just some steps involved in the full CNC process—suggests that much of the required knowledge remains hidden, uncoded, and experiential.

A Hands-on Demonstration on a Grey November Afternoon

My *first account* comes from the "hands-on day" at the 2017 annual networking meeting of the German-based association of open workshops in Nuremberg.[137] These networking meetings are open to the public. The meeting took place in Z-Bau – Haus der Gegenwartskultur (house of contemporary culture), a former military barracks in use by different cultural institutions since the early 2000s. One of them includes the makerspace Urban Lab which acts as a charitable organization to enable the local community in social projects. During my visit, Urban Lab operated entirely out of a repurposed and refurbished shipping container based in the garden of Z-Bau (see Fig. 4.2). What I found as a rather amusing accommodation has a very practical purpose of holding their vertical CNC mill—the only

[136] For philosopher of technology Carl Mitcham (1994), the model contradicts itself as "all of these are stages within the domain of skill as such," while the first two depend on the individual, whereas the upper three become "emancipated from individuality" (p. 196).
[137] 'Verbund Offene Werkstätten' is an association registered in Germany, but it includes several members from other European countries.

technology Urban Lab provides.[138] For the hands-on day, Urban Lab offered a small introduction in CNC milling split into two parts. We started with a roughly one-hour presentation on the milling process and some technical specifics in one of the Z-Bau rooms. The presentation was reasonably semi-structured allowing to take a specific direction based on other participants' insights or comments. It was through these comments that I could guess how much or little of CNC skills and knowledge people were bringing.

Fig. 4.2. Urban Lab's container in Z-Bau's garden.

The presentation quickly turned into a heated debate around the advantages and disadvantages of proprietary and open-source CNC software. Occasionally, the presenter, one of Urban Lab's co-owners, would return to his presentation realizing that some of us have little experience with the process as our baffled faces revealed. Then again, we were guided 'remotely' in the technical specifics of exporting a CAD model for milling from a dxf-file, and of using contours. Said explanations leave one with a blank face if one had never worked through the entire design and manufacturing with the machine process. My field notes on this presentation filled up with comments such as "[t]his refers to the level of detail of CAD drawings for milling," "Inkscape is more suitable," and a long list of CAD and CAM software brands but at the moment they made little sense to me. We moved on to the CAM

[138] Urban Lab's inventory is further supplemented through a joint project with Z-Bau in the form of an additional workshop space offering the standard maker technologies such as 3D printers, laser cutters, and electronics.

software, the role of on-screen milling simulation for error location, and the export of tool paths (G-code). The latter prompted a participant's question of how to interpret the tool path's direction of a complicated pattern such as a star-shaped drawing. This makerspace manager described how the CNC mill at her fab lab follows a rather unexpected tool path "by regularly jumping from side to side and point to point." Somebody in the group responded with "this is the logic of milling." Such vaguely technical descriptions recall Orr's (1996) telling of "war stories" by photocopier technicians which are configured on a range of materials—photocopier documentation such as handbooks, shared work stories over lunch and embodied experience of working with the machines. However, as Orr shows, these "war stories" make sense to someone who belongs to this mutual circle of knowledge.

For the second part of this demonstration, called "hands-on production," we all moved to the container in the garden. Separated into two spaces, the container holds the vertical CNC mill in one, while the other by the entrance is used for material storage and indoor meetings. Urban Lab's founding members showed us around and gave a brief introduction of the machine before proceeding with the actual milling. The CAD drawing of 84 wooden 'tennis racquets' in a 28 by 3 grid had already been designed and uploaded on the CNC mill computer. As it turned out, it had already been tested on a different occasion over the summer.[139] The container was tight, so we lined up along the wall across the machine to watch the milling, but many left quickly as the entire process took over an hour to complete. It became 'boring,' and noisy, to stand by all the time but CNC milling requires that its operator is on standby. Once milling finished, the actual "hands-on production" happened with those of us who remained around. We were finally involved in practical doing. Typical for CNC milling and 3D printing, pieces are never entirely cut but have supports on the side which require their final removal through post-production. In this case, it meant roughly cutting the racquets apart with a circular saw, and sanding them by hand. Finishing the 84 racquets in collaboration appeared as monotonous yet enjoyable and educative for apprehending the material aspects of CNC milling. It also demonstrates that full automation promised by digital fabrication is unattainable. The representation of making and digital fabrication propagated through images of 3D-printed objects or CNC-milled design furniture often misleads the understanding of the handcrafted processes behind that.

139 The demonstration thus corresponded to a staged public witnessing of one of Robert Boyle's experiments (Shapin & Schaffer, 1985).

After Work CNC Milling

Within a few days after the demo, I had signed up for a regular CNC milling training session at Fab Lab Munich. The session, offered to both members and non-members of the fab lab, certified for future working on the CNC mill. Training sessions in this space happen in the evenings or on the weekend as tutors are volunteers. For this one, we met for three hours on a late Monday evening. The time was spent directly at the machine used for the training. This specific CNC mill is a DIY desktop-size model.[140] Its advantage jokingly pointed out by the trainer, an autodidact with a background in mechanical engineering is that the mill has "the power to destroy itself," which is the case with almost any mill. I wondered what to make out of this comment. The idea of a self-destructing CNC mill felt less encouraging than he perhaps intended in order to show how little damage a novice could cause. At the same time, we were warned not to work with metal as this CNC mill had little power and would cause the machine's physical form to become distorted. The training so far was a lecture on hazards, both human and machine-provoked. This narrative continued warning us about the regular breakdown of milling tools with a recommendation to buy and bring our own.

Finishing the risks and hazards part of the training, we remained detached from hands-on training on the mill. The exposition focused on the typology of CNC milling processes, 2D CNC as in laser cutting and 3D CNC as in additive or subtractive manufacturing. Passing around a variety of fabricated objects to touch and see, the trainer used them to inform about different modalities of fabrication in CNC milling, but the conversation was carried away into technical specifics and individual participant's projects and backgrounds. The interaction with each other was limited as there was no common project to work on. The participants regularly put own interests in the foreground ignoring the brevity of the session. Feeling reminded of the time, the trainer moved on to explain the relevant components of the desktop CNC station and how to operate them: Which switch to turn on first, which is the 'red button' for shutting down the mill, where can we find other tools if we don't bring our own, and where to find a handbook if no one is around to ask for help.

He then jumped on to explain the two different directions of the spindle rotation—clockwise and and counter clockwise—by using a piece of wood with paper attached to it. The paper displayed a tiny path which had been milled using each direction, as well as hand-drawn Cartesian coordinates to illustrate the orientation of the mill's axes (see Fig. 4.3). As a tangible teaching object, this little piece of wood could be mounted easily on the mill bed and thus visualize the axes orientation without

[140] The beginner training and certification happens on this self-made/DIY machine, while members later use to work the Wabeco F1210C hs mill or the desktop Roland iModela.

requiring to imagine that. And if that failed, he showed us a trick using the left-hand fingers which interestingly was not transferable to the other two CNC mills I was trained on as coordinates depend on whether the CNC bed moves or not and in which direction. Again I found that the training was based on a lot of prerequisite experiential knowledge. A description as this one remains typically uncoded in textbooks, even the handbooks of CNC. Defining parameters and measures by way of the hand are residues of medieval construction practices (Ferguson, 1992; Jones, 1970; Lefèvre, 2004; McGee, 1999). Besides, the method appears contradictory to the precision and accuracy ascribed overall to CNC processes. However, as scholarship on material practice reveals some of that precision or accuracy becomes obscured by the dependence on embodied experience (Rosner, 2018).[141]

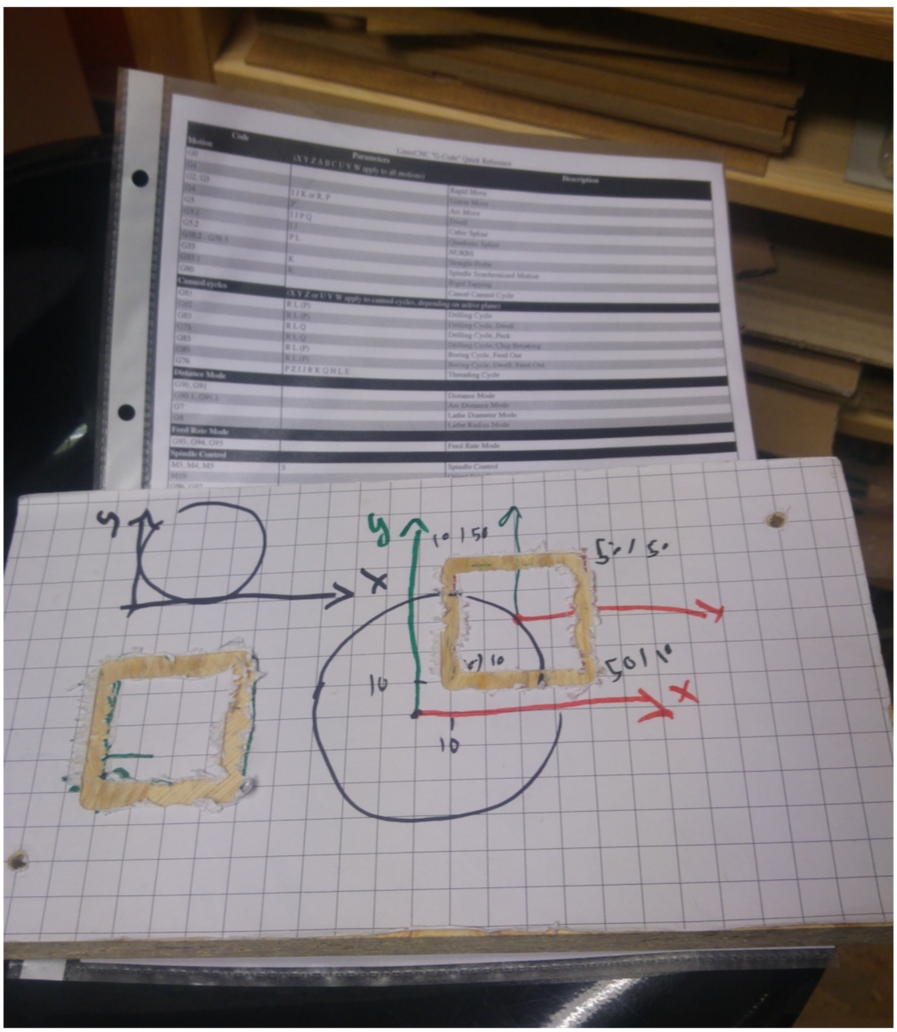

Fig. 4.3. Demonstrating clockwise and counter clockwise spindle directions in milling.

[141] Accuracy and precision are also features of Western science and technology, which have been ascribed by default as male domains.

Being told about the risks, the machine components, and the geometrical arrangement, we moved on to prepare the tool path for milling on the machine itself. Similar to the demo with the racquets, the trainer had already developed and tested a CAD model of a small boat. Using his model, he started the Linux-based CAM controller to discuss tool paths briefly and determine the milling operations we would apply onto the boat. The tool paths considered as automated by the CAM software are regularly snubbed from training sessions. Here as well the trainer referred to a two-page printout with the essential G-codes by noting we could always find in the drawer near the machine. The remainder of the session was embedded in a procedural demonstration: from uploading the CAD file into the CAM software, through the definition of the tool paths and their export, to setting up the machine specifics on CAM controller. As we were getting ready to mill together the small wooden boat—one for the entire group of four participants, the trainer realized that he had forgotten to demonstrate how to place a milling tool in the tool holder, how to release it, and how to tighten it onto the machine. Once each accomplished this intermediate hands-on exercise, we got on with milling the tiny boat with each one of us getting a chance to vacuum the wood chips manually. This three-hour unstructured demonstration rather than training a skill-forming exercise marked the end of my first training and thus allowed me to work on the machine on my own, without further supervision.

ShopBot-Specialist in Under Four Hours

The second training session happened about a month later at MakerSpace, a professionally and profit-oriented shared machine shop. Scheduled for three-and-a-half hours on a Sunday morning, this session titled "CNC wood mill ShopBot and Introduction in VCarve for Beginners" promised in the description that I would become a ShopBot specialist. As such, I would know the basic functions of CNC milling, safety measures, prepare tool paths in the ShopBot-specific CAM software VCarve (Vectric Carve), some NC programming, and the hands-on production of a wooden coaster. Moreover, after completion, the description promised that I could execute projects that require the highest precision, construct objects that can be produced automatically with CNC mill, and produce 3D forms that can be used as a base for deep drawing, a sheet metal forming process.

The trainer picked us up at the front office. Recalling my previous training, I assumed we would immediately go to the workshop with the ShopBot. Instead, the trainer brought us into a room full of computers used for software training as well as for members to prepare designs and tool paths. Over the next hour, each one of the participants followed an on-screen demonstration of the CAM software

VCarve in front of a computer. As part of ShopBot's original software bundling, most makerspaces offer training with that. VCarve serves as a CAM post-processor to prepare definitions for the NC-generator. The trainer thus noted that we could also use the CAM function of another software such as the proprietary and widely distributed Autodesk Fusion360. As this makerspace's specialty is to offer paid and costly courses, they tend to promote software for which they have the licenses. Unlike the previous two activities that I attended, here recommendations for open-source alternatives were not made. Instead, we were advised to download a trial version of either VCarve or Fusion360 on our private computers and work offline. If we had to prepare the tool paths, we could upload our offline files to the licensed computer at the workshop and convert them.

The instruction focused on the user interface setup in VCarve and the parameters requiring definition such as the work piece, the zero point, modeling resolution, and the interpolation resolution determining the model's fineness grade. He then advised us that NC operations are defined on the contours of the shape, basically how the respective contour is being handled. I recalled this step from the demonstration at Urban Lab. Besides, the trainer noted that the CNC mill requires a wood plank fixed on the milling table which is being 'sacrificed' during milling as the milling cutter go deeper than the work pieces. This requires a correct setup of the tool database. However, setting it up entails an advanced level of experience in working with different cutters and materials, especially as tool manufacturers avoid defining fixed values. Instead, the trainer points out that tool manufacturers recommend experimentation. This aspect suggests that machine-tool-material configurations would be different each time. I wondered how accuracy is achieved then. The conclusion I derived based on what I had observed and heard from other makers is that accuracy is achieved only by working with the same arrangement permanently, as each change would lead to slightly different results. Unfortunately, I could not ask the trainer as we were quickly moving from one topic to the next. But if we had more questions on technical details, the trainer referred to the internal Wiki that would provide an overview of the different processes, specifications, and materials. In other words, we would not need the embodied knowledge of materials but could draw on its codification.

The session was timed, so we turned our attention to the few common NC operations. As a numerically controlled process, a mill never executes two operations at one time. It works in single passes or cuts. The NC-processor thus breaks each operation into a single executable operation much like slicer software in 3D printing breaks down the entire model into single entities that are printed layer by layer. In this context, we also discussed the current and countercurrent direction of milling, and the role of the "last pass." The "last pass," as the name suggests, is the final one which allows improving any residue of cutting edges from the previous passes. The final three steps we learned include placing supports, naming the operation, and a simulation of the milling to test for possible errors. Finding it unclear what a file and what a pass is, one of the participants asked the trainer about a description of a standard tool path. He clarified that by using the example of milling one object with different milling cutters. As changing milling cutters during one pass is a complicated process, but not an impossible one, it is recommended to create separate files for each tool path and respectively each tool. In-between that tools can be changed on the mill. The trainer wrapped up the one-hour VCarve technical introduction, and we finally went to the workshop area with its different woodworking machines.

The hands-on machine introduction commenced with a presentation of both ShopBot mills: a small with a moving table and a fixed milling cutter, and a large and standard makerspace model with a movable milling cutter and fixed table. As we arranged around a work desk next to the large ShopBot with its computer station, the trainer explained the technical specifics of the workshop area—ventilation, electricity switching panel, all other machine switches. While we waited for the first step—the spindle warmup, he suggested to carry out the next one—screwing the work piece tightly onto the table. We started preparing the manual setup of the 'zero point' on the mill. The process involved both computer machine controls and an individual's hand-eye coordination. During the previous training session, I assumed that this way of setting up the zero point was conditional on the fact that the mill was a DIY model and could not come around implementing the proper automation. I did not expect that on the ShopBot. Being promoted as a high-precision machine that enables makers to access the means of professional production, I found the aspect of hand-eye coordination in working with a ShopBot incomparable to precision and accuracy. I puzzled about how machine precision is guaranteed in this case. Does machine precision depend on a scaled up production? But such questions are often misplaced in these makerspace training sessions. Quite often participants assume that this is how it is done and never question what precision and accuracy means and depends upon.

After the X-Y coordinates setup, we repeated the process for the Z-axis zero point. Whereas the X-Y axes rely on our bodily senses, the Z-axis is defined through technical means by using a special metal plate and alligator clips attached to the mill. When the mill makes electrical contact with the metal plate, this value is saved in the CAM application to set the Z-axis zero point height. Finally, the trainer demonstrated how to load the VCarve file and export the tool path before the actual milling started. In this session, similar to the previous one, we worked with a pre-designed and tested file for a wooden coaster (once again one for four participants). The trainer loaded the tool path of his design onto the CNC mill and then just observed the automated process. Instead of leaving us time to generate the tool path by ourselves and at least simulate the milling on the screen, his show-and-tell demonstration was considered sufficient to make us "specialists in the ShopBot." It was a highly priced and cut down training after which I definitely could not execute projects according to the workshop description requiring "highest precision," nor could I construct objects for CNC manufacturing as this requires the CAD design of those. At the very least, I knew how to produce 3D forms for deep drawing, whatever that meant. However, I accumulated a lot of background knowledge through the repetition of similar topics from these first two sessions. I still had one more to go, but the experiences so far lowered my expectations.

The Ultimate Experience

My final training session at Haus der Eigenarbeit (HEi) followed a week later. Scheduled as well on a Sunday, the training this time was set for six hours. I describe the CAD/CAM components of this training session and how CAD/CAM was explained as a full workflow in the previous chapter, thus I narrow the descriptions and discussions on that aspect. Instead, I recount how the course structure provided for the acquisition of specific CNC-related skills.

About to spend the next six hours together in a basement with machines, the trainer gathered us first upstairs around a table in the café-like entrance area. We introduced ourselves with the trainer going ahead. He mentioned that he dropped out of his physics studies and later enrolled in computer science. Being interested in the work of his constructor colleagues but also wanting to understand why design and construction were separated, he came to HEi to learn CNC milling technology a few hours ago. The HEi had a DIY model CNC model assembled together from other mills and offered training long before the current tech-centered maker cultures existed.[142] His curiosity got him involved in course instructions until he finally took over from the previous workshop supervisor. After our brief introductions, we all went down to the basement. The training began with a clarification of the relations between CAD-design and CAM-results in the CAD/CAM pipeline by giving the example that 2.5D design leads to 2.5D manufacturing. The training was focused on the machines and their operation. He noted that the HEi used a mill with a fixed bridge moving along the X- and Z-axes and a moving table along the Y-axis. In three previous sessions, nobody had seen a reason to explain this. There is a preconception about specific skills and knowledge being brought to these training sessions,

[142] Two senior members of the HEi had been collecting parts, assembling the mill and maintaining it for about 30 years before donating the completed one to the HEi.

regardless of whether they are titled as "Intro for Beginners" or not. In a way, the fact that one is interested in that, presumes that one must know about the technical specifics. But in this case, the trainer was considerate about different details that might need more explanation.

The mill he mentioned is "beginner-friendly" by being resistant to vibrations. It made me recall the comment from my first training at Fab Lab Munich about the self-destructing CNC mill. He then added that the direction of spindle rotation, clockwise and counter clockwise, is utterly flexible as they have not experienced any issues with either one of them. Returning to the design for milling, he elaborated that the difference between a 2.5D and 3D mill is how each handles three-dimensional objects. There are two versions of 2.5D processes—simple engraving/facing and V-Carve engraving. While the name 2.5D hints that the process is a hybrid between 2D and 3D, it is based on two distinct augmented 2D tool paths. 3D milling, on the other hand, refers to the handling of three-dimensional CAD files. These technical details are relevant for the CAD design of an object and its later translation into CAM but were partially left out in the previous two sessions. In the first training, we briefly touched upon that by way of demonstrating different milled objects and how mentioned the process by which those were milled. Since his prelude concluded, he asked us to take seats at the two desktop computer workstations. We moved on to NC programming and CAD design.

As noted in the previous chapter, this was the only session that dedicated time and effort in explaining tool path (G-code) programming but also including an exercise. G-code in most training sessions is mentioned in passing through a couple of standard tool paths but rarely by explaining them in their relationship to Cartesian coordinates, thus demonstrating what every single line of code calculates. The fact that G-code tends to be omitted is interesting and might have to do with the fact that on the one side it is a standardized programming language defined to be applicable in different countries through an ISO subset of codes. On the other, unlike in the 1950s and 1960s when G-code was manually written and processed through punch cards, in the present-day, it has become a fully automated process delegated entirely to the CAM/NC post-processors. Both language standardization and automation work as a general code of agreement which leads to the complete dismissal in learning. This aspect recalls the two comments made at the Urban Lab demonstration on the non-apprehension of how the mill processes each pass, and the "the logic of the mill." Such questions and answers reveal that the knowledge required for the handling of a complex machine such as the CNC mill is not attainable in a two to a three-hour training session, nor is it transferrable without the complex interaction of human, machine, material, and codified knowledge.

But this time it was different. After the trainer explained in detail the different tool paths and showed how they could be written manually in the NC processor, we had to write the tool path for a small 2D sketch of a house and a snowman as both figures include basic geometries, then simulate that, and in the final instance "mill" the figures with a small repurposed CNC mill. The small mill uses a pencil lead instead of a milling cutter to draw a picture on paper. The exercise has a two-fold function. First, it illustrates the different tool paths to increase a better understanding, and second, it diminishes the uneasiness around CNC mills. The combination of a highly automatized technology with noncomplex tools such as pencil and paper works as an instrument of translation. Besides, this exercise or our conversation about developing an appropriate curriculum in CNC milling over the lunch break work as boundary breakers that dissolve the top-down approach of teacher and student, or expert and novice.

After lunch, we focused on the CAD/CAM workflow and the actual milling. Instead of presenting that as separate steps to be accomplished, the trainer spoke of a workflow in the form of a linear model. He quickly sketched a diagram to illustrate what each entity generates. In technical and also machine-readable terms, the CAD software creates not only design in the form of a vector graphic or 3D model but also a .dxf-file or a .svg-file for an import into the CAM software. The post-processor then generates a file in the form of a tool path for thee import into the CNC mill (see Fig. 4.4). Sketching this process also helps introduce the two software components. After his thorough demonstration of key functions and techniques with the CAD software, he helped us prepare a 2.5D design of a small wooden box. He used the project to explain the essential tool paths—contour and pocket milling—and simulate the final milling in the CAM software. He advised us not to rely entirely on the same settings since a lot of the values set up before milling depend on personal experience and the interaction between machine, tools, material, and potential environment (for instance, Urban Lab's stored wood in the container is permanently exposed to atmospheric transformation).

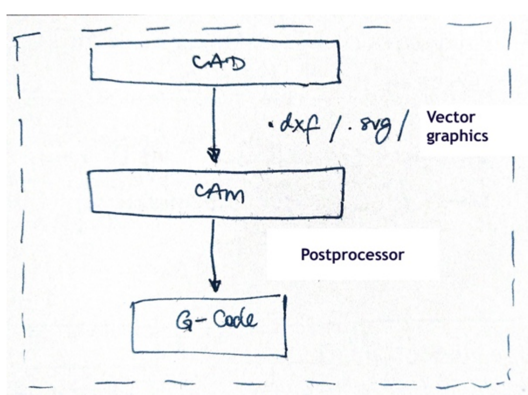

Fig. 4.4. The CAD/CAM process.

As time progressed, using his examples and the workpiece he provided, we worked in two small groups each to prepare the small containers and to grasp hands-on the CAD/CAM workflow. Once we finished the design and the tool paths, we moved to the CNC mill for a demonstration of its computer interface, the setup of the zero point, as well as safety measures. The zero point on this CNC mill is set up differently by using a bench vice. Finally, each one of us started milling their containers. For the first time, we did not work with a prepared model to which we had no relational experience, nor were we just observers of the milling. Instead, each one could measure material, design the box parts, set up the machine and data, and then finally mill the two parts. Observing the others also meant learning from another as we all went through the same process—we simulated an apprentice's mode of skill acquisition. The mutual exchange of a new experience becomes part of the skill-building as we learn a new process. This recalls what Niki told me about learning to work with the CNC mill at Machines Room. This process provides not only a training or functional descriptions given in a show-and-tell manner but also the opportunity to watch other makers gather experience through working with the same machine.

A Gendered Perspective on 'Everyone,' Skill and Expertise: Discussion

When I signed up for the first training at Fab Lab Munich, I expected to be the only woman participating. I already had been a member of this space for a few months to have a sense about their gender diversity. But for at least two other reasons, this training may not have been appealing to women in particular. First, it was scheduled on a weekday evening to accommodate working participants but also the trainer. This is standard practice across many shared machine shops but also more convenient for people without care-specific responsibilities. After all, the session only started at 7 o'clock in the evening and went on until after 10. What appears as mundane logistics, also works to exclude significant groups of people. Second, the limited size of this CNC mill suggests that its core application is for the manufacturing of small machine components. This aspect, though more specialist, was reflected in the other participants' background—mechanical engineering, electrical engineering, and hardware development.

A month later, at MakerSpace Garching, the pattern repeated. This time, however, I assumed to be perhaps joined by another woman and participants with more diverse professional backgrounds. The reason, precisely, was the type of CNC mill, the ShopBot. The size of the ShopBot allows for the fabrication of non-technical objects, often made of wood. The variety ranges but not limited to furniture, household commodities, and also upscale and customized leisure-ware such as sporting equipment. Partly because of these objects I suspected that more designers would join this training. Besides, this shared machine shop offers a list of courses for the digital fabrication of such customized objects. Yet on this snowy Sunday noon, I remained the only woman amid four male engineers. Their interest for the CNC mill all seemed related to their professional work in automotive engineering. While, in the past, I held job positions in different technological domains, and many times I had been the only woman on the team, thus making me more resilient to gendered work practices, I know that similar situations result in information presented as "dumbed down," too jargonistic, or by ignoring one's physical presence in order to demonstrate technical expertise and dominance. In this particular training, it was a blending of jargon and disregard.

When I went for my final training, I left my hopes for gender diversity at home. For the third consecutive time, there were three male participants—a computer scientist, a physicist, and an economist. But this time the interest of two of them, at least, demonstrated some diversity. The physicist was looking to learn about CNC milling as founding member of another local space building a CNC mill. The economist's intension was to build a crib for their unborn child. This motivation diversity also relates to this specific location. Founded in 1987, the Haus der Eigenarbeit aims to support the neighborhood in all possible ways. With its open workshops (woodworking, metalworking, ceramics, electronics, jewelry, and many more), guided supervision, and remarkably affordable pay-per-use fees, it serves as a "third place," but also as a workshop if one lacks space and tools, or even a place to pick up new skills for the job market. This is how I experienced this location over many afternoons and weeknights coming to work on a modular shelf. The boundaries between professional and amateur dissolved the moment one entered the door. Although I had been the only woman in the CNC milling course, the course format and information were impartial towards gender. There was no dumbing down or disregard for my presence. When information appeared as asserting tech jargon, the trainer immediately reassessed that. In other words, a shared machine shop's alignment with professional goals or social principles reflects how different forms of knowledge are gendered and thus decoded as a particular form of expertise.

In bringing these different accounts—distant, medial, and personal—into conversation, I underline the disagreement between the public rhetoric on skill and expertise needed to take part in making and digital fabrication and the actuality of these practices. On the one hand, as some of my interlocutors propose, these environments nurture precisely technical skills. On the other, the spaces themselves circulate inaccurate representations of skill and expertise in descriptions of courses and workshops as, for example, my training session with the ShopBot mill and VCarve indicates. Juxtaposing these different training sessions and analyzing their structural model discloses the discrepancies on the broader conceptions of "everybody," gender, technology, skill, expertise, and their social context. While individual cases drawn by my interviewees and the media exemplify the likelihood of expert acknowledgment outside the maker culture confines, they also allow for an interpretation as aspirational luminaries who reproduce a predominantly Western image of the self-made person. As such, these cases propagate profiles of technological innovation heroism known to silence different forms of knowledge and expertise that may matter for technological design, use, and understanding (Balsamo, 2011; Boeva & Foster, 2016; Rosner, 2018).

It also shuts out the critical fact that making and digital fabrication for amateurs or novices frequently remain on the level of technical learning of skills. My experience with learning CNC milling substantiates that. The participation, in particular, in open design development comes to an end for amateurs when the design and development necessitate aspects such as higher quality of production, complex designs, and professional tools which many of them are in a way (Oder & Petruschat, 2012). Then again, 'everybody's' participation also may never commence if descriptions, conversations, and environments feel unwelcoming or exclusionary as I foreground from my training experience. While my privileged position of an academic likely disqualifies me as 'everybody,' my decision to perform against the grain of heteronormative technical cultures by taking up CNC milling courses opens up trivialized perspectives. In all three training sessions, I remained the only woman among all participants and trainers. Even the hands-on day demonstration attracted a comparably small group of women—five in total—although the overall gender ratio was more balanced.[143] Such details are not surprising if one is acquainted with the demographics of CNC manufacturing technologies and their socio-technical context, as well as with maker cultures. Women have widely been restricted access to training in traditionally male work domains (Wajcman, 1991). But these details conflict the narrative of empowerment and democratization of means of production espoused across maker environments.[144] In reviewing the role of craft as female, domestic work, Alison Powell comments on the role of gender

143 Two women were fab lab managers. Other places such as Happylab's franchise have worked towards an equal ratio of male and female technical managers. Milan-based WeMake has also appointed female staff members in core technical positions.

144 The French online media outlet Makery for and about shared machine shops conducted an online survey on different job positions in maker communities in France and abroad. It focused on social, educational, and financial background. "Internationally, our typical fablabber is a young (27-year-old) man, university graduate, with a background in business or design," states the study (Claude, 2017). The community's demography was predictable as other previous studies (Make Media, 2014) have shown that. Yet, it captures the prevalent conditions in many of these communities.

in the stories that are made visible in technological cultures:

> I think there is a better story to tell about 'making' than this one, and that better story acknowledges the various ways that making is gendered and cultured. This seems obvious enough, but actually doesn't come through in many of the discussions of open movements. We need to acknowledge this as a research community—first, so we can acknowledge the innovations of cultures past, some of which are obscured because of the inattention to women's history. And second, so we can avoid essentializing gender and culture when we make recommendations for how to open knowledge or create knowledge sharing processes. (Powell, 2012b)

Understanding technology requires the reference to gender as feminist scholar Cynthia Cockburn points out (1985). Feminist scholars of science and technology have long investigated the strong alignments between technology and masculinity (Cockburn, 1985; Haraway, 1988; Cowan, 1983; Traweek, 1988; Wajcman, 1991). Sherry Turkle's notable account of computer identities (1984), for example, introduced the stereotype of "computer geek" which remains effective three decades later (Dunbar-Hester, 2016). As an up-to-date study on U. S. education makerspaces indicates, gender disparity presents itself even as a language misbalance: "Instructors primarily referred to male students as "geeks," "builders" and "designers" (never "boys"), but most frequently referred to female students as "girls" or even, "helpers" (Kim, Edouard, Alderfer, & Smith, 2018, p. 6).

When Debbie Chachra, an engineering professor, published her essay "Why I Am Not a Maker" (2015) in *Atlantic* magazine, her critique challenged the maker proponents. She argued that maker culture's focus on providing "access to the traditionally male domain of making [things]," and I would add to that STEM-oriented female education activities, promotes the idea that women should adapt to male cultures of work, thus decreasing the value of "the traditionally female domain of caregiving" (ibid.). Instead of lauding gendered technological knowledge and expertise, she called for recognition of "the caregivers" in our societies. Her comment reminded of what Marie from Copenhagen Maker told about the central topics of their festival. The festival was working together with a local educational institute to get girls involved in coding and other tech-related activities to counterbalance the gendered curriculum in Danish sloyd classes. She emphasized that boys are often more visible and active, even in public space. "We are being influenced by that as well," she adds (Mogensen, 2017). Here, again, making visible is construed as coming to terms with the norms of technical culture. As Sherry Turkle and Seymour Papert contend, "women are too often faced with the [...] choice of putting themselves at odds either with the cultural associations of the technology or with the cultural constructions of being a woman" (1990, p. 151).

Yet multiple examples within the contemporary technology spheres, for example, adafruit-founder Limor Fried, self-titled "queen of shitty robots" Simone Giertz, or artist Addie Wagenknecht, demonstrate the possibility of a middle ground between these oppositional identifications. WeMake in Milan has also advocated for gender diversity from its beginning by employing women with different professional backgrounds as trainers, giving them access to the technological facilities to learn and experiment, but also having them contribute with their specific skills and expertise to the array of activities. Chiara, one of their core staff members, brought in professional expertise in graphic design and personal expertise in knitting which she looked to combine.[145] Through WeMake's contributory model she acquired hands-on skills in laser cutting, collaborated with others to hack an industrial knitting machine, and began interpolating her personal interests into professional projects. Even small details such as a banner that hangs above the entrance, showing an illustration of a woman in front of an unspecifiable digital fabrication machine, substantiate WeMake's objective (see Fig. 4.5). Besides that, putting initiatives such as a digital fashion academy and the topics of digital knitting and open care at the front levels up what Chachra describes as feminine domains with the "computer geek" cultures of electronic hacking and 3D printing.

[145] Name changed.

Fig. 4.5. WeMake's banner hanging above the entrance area.

Sociologist of technology Judy Wajcman, however, stresses the importance of not conflating technology and technical skill as "inherently masculine" (1991, p. 38). "To say that technical competence is part of male gender identity, is not to presume that there is a coherent single form of masculinity," she argues (ibid., p. 39). Moreover, questioning the concept of "everybody" in maker rhetoric, as Wajcman suggests "ethnic and generational, as well as class differences produce different versions of masculinity" (ibid.). In other words, as she concludes that we cannot essentialize "men" and "masculinity," I insist, as my examples illustrate, that in the context of making and digital fabrication we cannot essentialize "everybody." What seems to be a "dilemma," offers paths to reflect on controversial and dominant paradigms such as "universality"—a model which Lucy Suchman (2011) attributes to Herbert Simon —or "genderless users." As feminist HCI scholar Shaowen Bardzell puts it: "How do we simultaneously serve real-world computing needs *and* avoid perpetuating the marginalization of women and indeed any group in technology?" (2010, p. 1304; original emphasis). Whether it is maker cultures or other technological domains, we need to listen attentively how contradictory conceptions of skill, expertise, gender, users, or technology get camouflaged under seemingly neutral labels, while under the surface conventional models are being reproduced.

Conclusion

The chapter began with the question of why making and digital fabrication seem preoccupied with a notion of non-expertise as both entry point and condition to its 'success.' Against that, the actual state reveals discrepancies about forms of expertise, the relationship to skill and experience, their legitimation, and their social embeddedness in technical practices and cultures. Take, for example, my two field sites in Milan. Both, WeMake and OpenDot, are legitimate authorities on making, digital fabrication, and open source practices. They are often participants in public debates, professional events, and communal projects organized by the city council, professional networks, or tech companies. These invitations, however, depend on two interrelated factors. On the one side, being perhaps the leading shared machine shops in the city, they are considered the experts on these topics. On the other, having been around for only four years, their expertise also draws on cultivated and existing relationships that have been shaped over years of professional work practice before establishing these sites. In other words, the situatedness, or as Jasanoff (2003) points out, the socio-political, cultural, and historical context, of these sites' expertise is twofold—one from within and the other from the outside. Although a redistribution of authority or new forms of expertise is possibly happening, it cannot wholly undermine the position of the institution. Hackers but also makers establish communities with their requirements for acceptance, working along certified institutions, sometimes even in a dialogue with them. Even as these communities and their practices may present an extension of what Schön (1983) considered a decline in public trust of professionals, they define themselves in relation to established forms of expertise and professional knowledge.

In this chapter, therefore, I argued that maker cultures blend perceptions of access and effortless learning of skills with the exposition of advanced projects that help demonstrate its expert status. Moreover, I proposed that expertise by making like other distinctive forms of expertise depends on a local and situational context to validate itself as such. As such, it reinforces own 'ecology of expertise' by referring to authorized sites of knowledge and skill and implementing them as credential systems for expertise so people can become proficient makers in the first places.[146] Alongside its situatedness, the chapter asserted that accounting for its foundations in skill learning and experience provides a more appropriate and inclusive definition of expertise by making. Finally, in challenging the framing of makers and inquisitive individuals as 'everyone,' the discussion focused on gendered traditions of expertise, their implicitness in technical practices, and the potential pitfalls of degendering by promoting female participation in them instead of accounting for other skills. To trouble the norms and to puncture the public rhetoric, I suggest that such spaces begin by eliminating the strong claim that their spaces are for everyone. Instead, to stress their different knowledges and expertise, shared machine shops should come up with more accurate depictions of their user groups and objectives.

[146] I am grateful to Edward Jones-Imhotep for this articulation.

Chapter 5.

Infrastructural Effects on Making as a Design Practice

> Infrastructures are metapragmatic objects, signs of themselves deployed in particular circulatory regimes to establish sets of effects.
>
> —Brian Larkin, 2013, p. 336

> When we think of spaces and dynamics, how can we concatenate knowledge, skills and labor in the making of new worlds? Worlds in which the improbable can happen. […] What we need is another path, possibly made from stitching experiences already at hand. Attributing the proper value to embodied knowledge. Making people work together. Transforming matter through collaborative ways. Removing garbage from the trash can. And, please, expecting (and making room for) the unpredictable.
>
> —Felipe Fonseca, 2017

Every day for a week, I walked by this poster in London's Bethnal Green, home of Machines Room (see Fig. 5.1). With the unforeseen clear and balmy January weather, it carried a notion of triumph. Fixed on the brick walls of William Alsop's architecture studio, an unconventional figure with his practice and stance as my impromptu studio visit in 2016 gave away, the poster hangs across from a 'Hackney' repair shop—the correct label for London's black cabs—and in walkable distance to Calverts, a worker's printing cooperative in operation for forty years.[147] On first impressions, the poster and the locations represent common elements of contemporary urban life: nothing obviously remarkable. However, a closer look at the bottom of the poster uncovers one name: William Morris, famous Victorian pattern designer, founding figure of the Arts and Crafts Movement, and early utopianist and socialist.

Fig. 5.1. Poster on Vyner Street, London

[147] A lot can be written about this impromptu visit at aLL design and Will Alsop (1947-2018) but the two things that immediately stood out to me were seeing a small model of the Sharp Centre for Design, Ontario College of Art and Design's unparalleled building in downtown Toronto, and the large canvases with Alsop's work-in-progress paintings. Alsop encouraged his employees to follow their yearnings and probe around with methods, materials, and theory.

That revelation transformed the poster's meaning for me, evoking the possibility of countercultural existence amid neoliberal societies. Indeed, London's East End, and, in particular, the areas of Hackney and Bethnal Green—with their vibrant culture and eclectic mix of local traditions, alternative communities, and venturing forward-looking projects—have become a center of attention for commercial interests.

The poster's urban context also invokes a broader notion of infrastructure as an invisible, almost disappearing layer upon which other interactions and arrangements depend. "[I]nfrastructure is something that emerges for people in practice, connected to activities and structures," as Susan Leigh Star and Karen Ruhleder write (1996, p. 112). Infrastructures endure in social and material relationships. Although my research on cultivated environments for making and digital fabrication was immersed in all kinds of arrangements that count as infrastructures, I initially perceived them as networks. During my research in London in September 2016, I came across the Maker Mile guided tour in the London Design Festival program (see Fig. 5.2). Following a recommendation to visit Machines Room, this tour coincidentally set out at the makerspace and included other familiar maker-related businesses.[148] As the tour unfolded, I considered the arrangement of these different places, their stories of sharing machines, and the personal relationships as a network and not as an infrastructure for making.[149]

Fig. 5.2. The map of the Maker Mile and announcement of Maker Mile tour for LDF 2016. Photo credit: makermile.cc; author.

[148] Notable examples include Technology Will Save Us, Sugru, and Opendesk.
[149] I understand "network" as a surface appearance that is intentionally established by different actors to support the functioning of their endeavors. Meanwhile, hard and soft infrastructure resides underneath and is available to be employed regardless of intention.

Paying attention to infrastructure as a multidisciplinary approach located 'below the surface,' however, allows the exposure of nuances instead of just binaries. The nuances and shades provided by the infrastructural lens help interpret the motion underneath the surface of the broader rhetoric around blurring the boundaries between professional and amateur making or traditional technology production and new, alternative practices. Through the material manifestations of mundane urban objects like doors, signage, and windows, maker environments both stabilize their local position and order their interaction with people (Denis & Pontille, 2015). An absent door sign in the case of a hackerspace ensures identity protection against raids by the authorities, while at a makerspace or a fab lab it comes across as a deliberate act of professional secrecy or simply an exclusion of those unrelated to their practice. In his ethnography of Swedish design, anthropologist Keith Murphy observes that design studios unlike galleries and shops serve as "place[s] for labor, not for display" (2015, p. 140). In following his statement, I looked specifically at how makerspaces deemed public and unconventional gradually recreate demarcations such as those separating work and community spaces. I argue that making as a design practice, rather than supporting alternative possibilities for fabrication, reproduces conventional standards through the infrastructural effects of these commonplace materialities and social relations. In doing so, this chapter asks how do mundane materialities that include doors and signs construct our interaction with places for making?

To support my argument, I draw upon empirical snapshots from my fieldwork. These snapshots demonstrate how specific material and social constituents of infrastructure such as external architecture, internal spatial arrangements, and regulation of entry in maker environments condition their functioning and public perception. As such, I seek to draw out the overlaps—the "seams" (Vertesi, 2014b)—among these infrastructural elements. In what follows, I trace the theoretical foundations of Star and Ruhleder's infrastructure framework as a relational and social concept as well as its successive applications and variations. Foreshadowing core aspects of infrastructure through this theoretical review, in the next section I recount different succinct sketches of maker infrastructure through vignettes and discussions gathered at my field sites and other activities such as maker-related conferences, research events, and informal conversations. By piecing together the less apparent yet constitutive elements of maker infrastructures, seemingly mundane to the people closely involved, I focus on how they influence questions of visibility and opacity, inclusion and exclusion, and networks and alliances. Infrastructures as methods of classification selectively include and exclude (Bowker & Star, 1999). Last, in moving forward, I illustrate through empirical examples how the social effects of maker infrastructure create existing "alternatives." Rather than simply assess the socio-material maker infrastructures, which I discussed earlier, as barring universal participation, this section indicates how my studied actors and activities respond to contentious social conditions at maker environments that replicate societal norms such as age and gender exclusion or commercialization in technology production.

Understanding Infrastructure

How does one study dispersed and decentralized systems, technologies, even communities? What elements to search after, the similarities or the contradictions? A number of studies have reviewed the effects of technologies on the organization of society, environment, and practices from their unmistakably physical manifestations (Dow-Schüll, 2014; Hughes, 1983; Starosielski, 2015; Winner, 1980) to information-based collaborations (Brown & Duguid, 1994; Star, 1991; Star & Ruhleder, 1996; Vertesi, 2014a, 2014b). These and other studies shaped the methodological work of what has become known as infrastructural studies. In particular, Susan Leigh Star and Karen Ruhleder's ethnographic study of the collaboration of biologists and computer scientists in the Worm Community System devised the foundational framework for the concept of infrastructure. In their "Steps Toward an Ecology of Infrastructure" (1996), they argued that since decentralized information technologies oscillate between common standards (standardization) and local, tailored solutions (customization), "some sort of infrastructure is needed" (p. 112). In describing the different practices and demands of the two distinct communities, their work offered an analytical framework and vocabulary to approach relational matters between "large-scale infrastructure" and the organizational changes occurring through its implementation. Indicative of movement, "[i]nfrastructure is not inert but rather infused with social meanings and reflective of larger priorities and attentions" (Howe et al., 2016, p. 548).

Critical about insufficient nuances of common interpretations that define infrastructure as this "invisible" or disappearing thing upon which other things depend, always available yet transparent, Star and Ruhleder emphasized its relational qualities. "[I]nfrastructure is something that emerges for people in practice, connected to activities and structures," they write (1996). What we likely consider as an infrastructure emerges "in relation to organized practices" (ibid., p. 113). Building upon Thomas Hughes' work on large scale electricity networks (1983; 1989), infrastructure as an analytical framework articulates the elements being changed and not just their drivers of change—agents and politics. In asking when and not what is an infrastructure, Star and Ruhleder outlined the multiple dimensions that define its "substance" (1996). An infrastructure resides within existing socio-technical structures and provisions and needs not to be rediscovered; it is embedded and transparent. It is configured and configures the practices and standards of a specific community; thus community membership affords its learning. An infrastructure expands on an existing backbone and inherits its virtues and faults to move beyond a single occurrence. Finally, it becomes detectable when it breaks: "Infrastructure is not always "infra," it seems" (Howe et al., 2016, p. 552).

A characteristic feature of infrastructure, breakdown defines much of the scholarship. But breaking down as HCI scholar Stephanie Steinhardt demonstrates with her ethnographic fieldwork on large-scale oceanographic infrastructure could be consciously pursued (2016). In Star's terms (1999), perceiving break down as intentional is conditional on the interaction. One person's functioning infrastructure is a break down for another, or as Steinhardt writes: "Breaking down is concerned with the unraveling of systems as a thoughtful process and not simply a clean break that requires fixing" (2016, p. 2199). I return to this idea of an intentional activity that manifests in a "thoughtful process" in my empirical snapshots. Invisibility and the corresponding breakdown, however, are only two of the many aspects of infrastructure. Infrastructures operate on many levels simultaneously (Larkin, 2013). Likewise, sociologist Janet Vertesi proposes the complementary vocabulary of "seams" for studying contemporary environments that involve different coevolving, and deviant infrastructures used by people at the same time (2014b).[150] The challenge presents itself, as she argues, in exploring the heterogeneity of these infrastructures while looking closely on the "actors and their practices at the local level" (ibid., pp. 267-8); thus she proposes "seams" as a micro-level border of interaction.

Infrastructures further become sculpted within the paradox of local and global, or universal depending on the context. For Star and Ruhleder, "It becomes transparent as local variations are folded into organizational changes, and becomes an unambiguous home—for somebody. This is neither a physical location, nor a permanent one, but a working relation since no home is universal […]" (1996, p. 114). Attending to the somewhat 'boring,' mundane elements of infrastructure, in a later essay, Star (1999) identifies other challenges in studying infrastructure and how to confront them possibly. These challenges point to questions of research method. For instance, in an infrastructure how do we know it exists and is complete? What and who becomes affected by its standardization? How does standardization become customized? These methodological questions, as she proposes, are noteworthy. I return to them in the discussion of the empirical snapshots to challenge both mine and my field site's assumptions about how a maker infrastructure looks like and what work it fulfills.

[150] Vertesi imports the language of seams, seamlessness, and seamfulness from HCI and design research on ubiquitous computing (see Chalmers & Garetti, 2004; Dourish & Bell, 2011).

Social Textures of Maker Infrastructure: On Gateways, Storefronts, and Supports

Studying geographically dispersed environments for making and digital fabrication presents a lesson in navigation through physical space and the recognition of how architecture interweaves in these experiences. Despite the ubiquity of mobile communication devices and what they facilitate, I prefer to work with an analog map of the specific city and area, drawing on my ability to discern specific elements on this map, and memorizing street names and house number.[151] But how does that transfer to the study of maker environments? One answer addresses the traceability of these places by 'newcomers.' Here I use the term newcomer not as presented in the previous chapter (*Chapter 4*) but to cover broadly individuals who have to interact with this place in any possible manner. In my case, finding these sites and their external appearance had a persisting impact on my analysis of the interactions underneath. For example, visiting for the first time Fab Lab Torino and the Arduino office, both located in the same building, I found myself in the everyday situation of not finding a particular place:

> I had written down the address [Via Egeo 16] and looked up the route from the subway station before I left. I knew Via Egeo is a dead-end street, and that the fab lab comes just before the street ends. The neighborhood looks like a former industrial zone, a bit worn off, not much else going on around. The situation is the same on Via Egeo: a row of buildings on the right, the tracks on the left. So I turn into Via Egeo and begin looking for the house with number 16. The first building I pass by is a defunct factory; the next one looks like a repurposed warehouse. I walk by its entrance door, but it has no number or sign, so I keep walking. Within a short distance, a more massive gate follows, again without a number or sign. I almost reach the end of the street. Around the corner, I recognize the entrance to Toolbox, a local coworking space, and I immediately knew I must have walked by, so I turn around. I keep walking until the same door. It's a short street. I recheck my notes for the house number. I inspect the door in case I missed something. I turn around again to head back to Toolbox and ask for help when I hear people talking and machine noise coming out of an open window. It is the familiar sound of 3D printers suggestive that *this must the place*. But I can't find its entrance. The street isn't busy at two in the afternoon, on a weekday, quite the opposite. But I see another person on the street and approach him. I ask with my rudimentary Italian if he knows where the fab lab or Arduino is located. Affirmative, he points to the one door I kept walking around. Not only this but he miraculously opens it. Stupefied by the situation, I mumble a "Grazie Mille!" and walk in. But inside the search continues. Standing by myself in a staircase surrounded by closed doors without signs, it is unclear where to go and find my interview partner. I knock on one closed door, but nobody opens. The stairs going up have no directions except large lettering on the wall saying "Guests" (see Fig. 5.3). I take that as my only option; I guess I am a guest and walk up. Passing by Casa Jasmina [Arduino's Internet of Things apartment], finally, on the third floor, I recognize Arduino's logo. […]
>
> Later going back downstairs with Alessandro for a tour, I learn that the locked door is the entrance to Fab Lab Torino. […] I also realize that he didn't provide any directions assuming probably that I would look them up online. (Fieldnotes, September 14, 2016)

[151] In this position, I have always remained aware that an experience utterly void of technological mediation is impossible (see Vertesi, 2008).

Fig. 5.3. The staircase between Arduino's office, Fab Lab Torino, and Casa Jasmina.

Recalling Steinhardt's assertion that "an individual component of an infrastructure can be breaking down yet the whole infrastructure remains [...]" (2016, p. 2199), I consider this experience as a moment of breakdown. The effects created by this infrastructural breakdown are only revealing for those outside this particular community delineated by its standards and norms of practice. In other words, the breakdown although relational depends on its personal evaluation. To recall Star (1999), one individual's success is another's failure.

Although this fieldwork snapshot marks a unique situation, in placing it in the broader framework of accessibility and visibility advocated by maker cultures, it converts from a moment of being lost to one of withholding information. Most times the difficulty of finding a site, for me, hinges on the fact of being a stranger in a new city rather than on lacking indicators such as door signage. *Doors, signage, facades*, all elements of architecture, form gateways. Similar to urban wayfinding systems, they shape the environment through specific modes of ordering (Denis & Pontille, 2015; Farías & Bender, 2010). Doors, in particular, as media theorist Bernhard Siegert interprets them, "process the guiding difference between […] inside and outside. They simultaneously thematize this distinction and thereby establish a system that is made of the operations of opening and closing" (2012, p. 8). The absence of an indication of this field site's offline location produces a boundary demarcation between distinct communities as well (Gieryn, 1983). The reason why this site had abandoned the exterior appearance remained unresolved to me. When I told the community manager that I had trouble finding the location since the facade missed a sign and perhaps others could eventually struggle with that as well, this seemed reasonably unproblematic to him. This indifference recalls one of the dimensions of infrastructures—the requirement for membership through a community of practice. Drawing on Lave and Wenger's concept (1992), Star and Ruhleder propose that "[t]he taken-for-grantedness and organizational arrangements is a *sine qua non* of membership in a community of practice" (1996, p. 113; original emphasis). Fab Lab Torino, the Arduino office, also the Casa Jasmina Internet of Things (IoT) apartment, form such community that seems imperceptive for the effects of its infrastructural arrangement via more mundane things such as door signs and facades.

The absence of external and visible indicators at this location possibly relates to the fact that both fab lab and the IoT apartment emerged as research projects by Arduino. These projects developed out of a business model that nevertheless builds upon a narrative of openness embedded in Arduino's open source environment. These layers of "infra-structural" information indicate that the maker cultures' mandate of opening up to a broader audience functions instrumentally rather than being the aspiration for by this place and many others as well. Indeed, the announcement made by Fab Lab Berlin at the end of 2017 that the space will go "into hibernation" for the first part of the following year, and access will be provided through membership only, after years of unlimited open admission to its premises, reifies this conception. I will return to the Fab Lab Berlin and its practice of openness later in this section.

Experiences as this fieldwork snapshot reoccurred, and often the blame for failing to find something is ascribed to the person searching a site. However, it is through the interaction with infrastructural elements that proposes its inconspicuous role for having a promising experience. Another fieldwork example supports this assumption. In fall 2016, I joint a pre-registered tour of Makerversity, a professional makerspace located in the vaults of Somerset House in Londons' City, to find out that a makerspace reproduces the same principles of private organizations. From the beginning, the site's homepage and the reluctant communication with its staff members over months proliferated a secretive appearance. Scheduled for a Thursday afternoon, my ticket stated that the tour's meeting point is inside the Somerset House's New Wing entrance. With its notable size and many entrances, locating the correct one signals a challenge. Besides, the absence of a sign for Makerversity on the street or a floor plan inside the hallway attests to that. In such moments, we likely turn for help to mobile technology or a locally knowledgeable person. Back then I chose the latter option and headed to the counter with its security staff when right there I discerned a small sign behind it (see Fig. 5.4). This sign with Makerversity's logo explains that one either has an arranged appointment with a member of the makerspace or should ask the counter to call the Makerversity staff. I asked for help, explaining the reason for my visit. "Makerversity, what?" was their reply. The confusion continued even when other registered tour participants joined me until a Makerversity staff member appeared.

The tour group followed this person to the makerspace. As we reached the first door—just a passage—that opened only via an access card, this site reaffirmed its closure to the public. As a professional makerspace and coworking space, in fact, it promises its members the opportunity for undisturbed working. With its indiscernible location within Somerset House, however, the public cannot interrupt the daily business regardless. At the same time, Makerversity emphasizes the invaluable role of education through making and fabrication and the need to engage younger generations in these processes. But its particular location complicates that goal. The discrepancy of a location in London's City sets barriers for those who cannot afford to commute and join it through a paid membership. A makerspace's urban location, in fact, impacts the costs of fees. On the other side, Makerversity's provision of fabrication machines and workshops disqualifies from a main floor location in Somerset House. It requires being situated in its vaults thus concealing its existence. Regardless, these technical prerequisites cannot justify an absence of visible signs apart from the small one near the counter. Rather, they are indicative for a culture with a heterogeneous, complicated, and interwoven identity on the "seams" between open source values, hacking with its multiple inclinations, aspired professionalism with its architectural representations, and certain "progressive" morals.

Fig. 5.4. Entrance signage at Makerversity in Somerset House, London.

However, restrictions subject to infrastructure get applied to members as well. Often makerspaces and hackerspaces, rather than fab labs, are based on systems of vouching for other members if they want to join and use a space. The practice draws on the subversive traditions of hacking and a need to protect members' identities and activities. Regardless, within less 'rebellious' places these mechanisms are maintained as a result of other limitations, for example, a non-existent door opening system or a volunteer-based governance model. Such limitations paradoxically could go as far as restricting the access to existing members. At Fab Lab Munich, for example, where I was a member for a year, paying a monthly fee, access works through a kind of vouching system. It requires either arranging an appointment with someone who already has a credible status or coming to work during the regular Monday evening members' meeting to gain credibility. Applying this policy restricts members less committed to active club participation. Compared to Makerversity, however, this space holds no claim to professional objectives. The restrictive access policy works towards the identification of shadow members who tend to use the space for its technical infrastructure and without a contribution for building up community values. However, precisely these community values become defined by the rules of one site's governing board and not according to democratic principles.[152]

Although restricting access often works to define communities of practice, imposing rules on door access, in my opinion, constrains community rather than sustains it. The few times I relied on this space to work on a project, whether it was to repair a broken circuit board of a washer or to solder multiple jumper wires on LEDs for a hacking workshop, having to set a fixed time instead arranging around my schedule discouraged my ambition to become an active community member. The door as a gateway to the space became a gateway to making. As Larkin asserts in the opening quote of the chapter, these social infrastructures produce multiple "sets of effects" (2013, p. 336). I had many similar encounters with the infrastructural "sets of effects" in my fieldwork. As a relational concept, they require a profoundly contextual analysis by considering all possible dimensions and layers. Hence, I resist assessing the three previous snapshots as downright negative as such assessment entails the reproduction of a false binary, namely of good and bad. But treating the assessment as a binary and a categorical act seems inevitable (Larkin, 2013; Howe et al., 2016). The notions of openness/visibility and closure/opacity already impose binary values embedded in discussions on the governance, spatial arrangement, and public appearance of these places. Nonetheless, as I proposed in the chapter's introduction, any internal and external reflection proposes that the idea of maker infrastructure is comparatively nuanced.

For example, while Fab Lab Berlin signaled their "hibernation" phase, which would restrict access to members only, for several years the space had always been open to everyone in need of a space to work; that despite their gleaming and professional interior appearance evocative for the 'new economy.' When I approached Fab Lab Berlin as a potential field site, I expected that in order to get regular access to the space I would need to introduce myself to staff and resident members formally, and possibly receive a key or access card. The opposite was the case. I was told I can come whenever I want and can. This practice, however, turned out to be the practice for everyone else interested in the space as well. The doors were open during its regular business hours, and one could potentially walk in, sit down at a table, and work on their projects. This approach described their community-building strategy. If one wanted to work with the digital fabrication technology, a closer interaction

152 On the design and governance of hackerspaces and makerspaces, see maxigas, 2014; Davies, 2017.

would be required. Considering this openness that led to a community of several hundred members, the decision to restrict access at some point seemed anticipated.[153] Maker and digital fabrication environments as socio-technical systems require persistent alignment and realignment "in ways appropriate for the local membership" (Vertesi, 2014b, p. 274). Vertesi's vocabulary of seams, seamfulness, and seamlessness emphasizes the "actors' agency in the context of multi-infrastructural environments" (ibid., p. 277) by creating temporary states of alignment between often conflicting elements. As a bystander, I hold back from arguing that the absence of visible exterior signage or restrictive door policies is entirely in contradiction to the values of maker cultures. Instead, these elements of infrastructure instigate heterogeneous effects within their contextual backgrounds. At Makerversity, these elements imply a distinction from more leisurely oriented makerspaces while guaranteeing an undisturbed work environment to its members. For Fab Lab Berlin, a temporary limitation of access appeases its regular members to avoid their departure and relocation to another site.

The absence of a door sign at a design-centered makerspace, for example, also allows for an interpretation as "bad design" that could be changed to make them more inclusive and open if that is their overall objective. The hiddenness or obscured visibility of makerspaces, however, communicate a particular value to the outside world—what appears as hidden and covered is also what appeals to others. The direct lineage between many makerspaces on one hand, and hackerspaces on the other, indicates that active and potential members seek these communities for the prospect of a hidden and protected undertaking (Lindtner, 2015). The three examples brought up here from my fieldwork have different and nuanced reasons for their spaces to be hidden or become restricted, yet not entirely invisible. The typology of makerspaces also translates into different visibility. Corporate and institutional makerspaces such as Makerversity perhaps prefer a hidden appearance, but that could be determined by the physical location as well. The technical parameters of digital fabrication technologies by requiring larger property area and limited restrictions through zoning laws often reduce the visibility of these places. Fab Lab Torino probably falls victim to its embeddedness within Arduino's offices rather than deliberately being hidden. Meanwhile, Fab Lab Berlin by residing in a newly constructed building incorporate openness into the architecture. Here the value of hiddenness, instead, translates into the social infrastructures of the makerspace as I discuss later. For community-oriented DIY and underground spaces such as, for example, feminist hackerspaces, their hiddenness

[153] Both the former fab lab manager and the fab lab's strategical manager stated that their membership exceeds over two thousand people. However, this number is difficult to measure as many like myself never registered as official members.

yields protection from norms and values that marginalize their sociocultural and technological interests.

Visibility and hiddenness as I alluded to in the previous examples connect to the materiality of infrastructure as well. In his historiography of the *materiality of doors* and their semiotics, Siegert poses the following question: "How important or how disturbing is the making visible of the distinction between inside and outside in urban architecture?" (2012, p. 17). This question points to the materiality of glass doors. Glass as an element of visibility has different effects on infrastructure. By allowing to look in, it suggests that nothing reserved or fraudulent happens inside the space. At the same time, it imposes behavioural standards upon the people visible from the outside (Shapin, 1988). "Something can become visible at a spot where it is not located," comments Siegert (2012). In an environment such as a makerspace, to recall Gell's terminology (1994), one way glass performs is by enchanting. The choice to operate in a seemingly 'transparent' space reveals and conceals. A number of my field sites are located in former store properties which exposes their working to passersby. It demands, therefore, a permanent interaction between inside and outside through the interface of the storefront. Counter to some of my other field sites that restrict their public exposure to a sign, this interaction becomes evocative and appealing to the maker narrative of 'everyone.' In other words, the materiality communicates both the technical and social infrastructure of maker environments.

For example, in three instances, the spaces were located in such premises. The community-oriented Maker Austria in Vienna's Margareten district, a densely populated and diverse residential area, deploys its two front shop windows not only to demonstrate projects but to expose the interior spatial design. While the space's left side of the entrance is dedicated to electronic prototyping and 3D printing, the right one is used for textile and less technical projects. This spatial organization is reflected in the decoration of the respective windows to attract and explain the purpose of this environment to outsiders and people unacquainted with maker cultures. For Maker Austria, this arrangement is necessary because the street lacks significant traffic of pedestrians despite the district's high population. When the Happylab franchise opened their latest location in Berlin in 2016, they had little problems with exposure at all. Located on the corner to a busy central street, accessible by different means of transportation, the large storefront connected them immediately with the existing urban infrastructure and the residents. The effort Happylab needed to invest was rather in establishing a community to inhabit a staggering empty interior, void of machines situated in smaller closed rooms—not what outsiders could see through the window front.

Being located in a storefront-type of space, however, is not an immediate invitation to enter it. Instead, it presents a form of threshold that constitutes our knowledge about a space as the spatial organization required to validate scientific experiments in seventeenth-century England illustrate (Shapin, 1988). Material thresholds are "put in place and maintained by social decision and convention," Shapin argues (ibid., pp. 374-5). Many urban places, visible from the outside, are professional offices or businesses remaining closed for externals unless interaction is mandated. The materiality of glass, therefore, affords and interferes as Dylan at MAKLab describes the interactions revolving around one of their Glaswegian location's architecture:

> *for the general public, a lot of time, this is a very busy walk pathway. A lot of people will just be walking in, and we're still having a bit of trouble about letting people know that it's an open studio and that they can just walk in. A lot of people will walk past a couple times and then walk back and go "Am I allowed to come in?" It's like, "Yeah." I'm working on something at the moment, hopefully opening up a shop so it gives the idea [to people], "Oh, you can just walk in and browse.* (Rand, 2017)

At MAKLab, the windows, though sparsely decorated, were regularly rearranged to allow people walking by to discern what happens inside of it.[154] The concept of a shop was often implemented in some of my field sites such as Machines Room and WeMake, where designers composed part of the membership. Given its previous tenancy as a guitar factory and therefore being a sizeable space, Vancouver's MakerLabs includes as part of its interior design a store and a gallery of its members' products and projects right at the entrance. This spatial arrangement points to the possibilities that this site presents but remaining unconditional of the technologies behind that. The success of this type of enterprise, however, is contingent upon a site's urban location. Usually professionally-aligned makerspaces, in particular, those with industrial digital fabrication technologies, reside outside residential areas in commercial zones, office buildings, or back alleys. But even launching a 'DIY maker shop' in a mall to offer smaller products and services offers no guarantee for its acceptance by a local community as OpenDot's Makerland in Monza demonstrates (Ferri, 2016). Instead, it defies the practices and standards within the established infrastructure of the commercial mall.

Interior spatial arrangements as material infrastructure further reflect a community's composition. For example, the emergence of Milan's OpenDot out of the design collective dotdotdot's business needs and the embeddedness of one within the other transfigures the interaction with the physical space. In this case, all larger and noisier fabrication technologies are placed at the entrance while the design studio's office area is at the opposite end of that. The intermediary and largest area is a

[154] The minimal display also ensured having permanent daylight within the space.

communal co-working space for the full-time affiliates of OpenDot (see Fig. 5.5). This core group further forms what other makerspaces refer to as a governing board. This spatial arrangement suggests that the fabrication area works as a boundary and "obligatory passage point" simultaneously (Callon, 1986). For those interested in digital fabrication, the interaction possibly ends at this point, while a person involved in matters of affair with the design collective would find themselves in all these areas. The spatial arrangement also directs the inside/outside focus of the space. In fact, it could be said that it frames the amateur (on the other rim) and professional (in the nucleus) distinction between its users. However, OpenDot's interaction with amateurs and new members from outside has been limited. I recall during a dinner with one of its core group members when they noted that OpenDot's growth out of the design collective not only brought an existing professional network, but maintains their strong ties to its professional members and partners to receive funding and develop new projects. This objective is reflected clearly on their website: "where alternative models of innovation are generated to satisfy the needs of companies, institutions and professionals."[155]

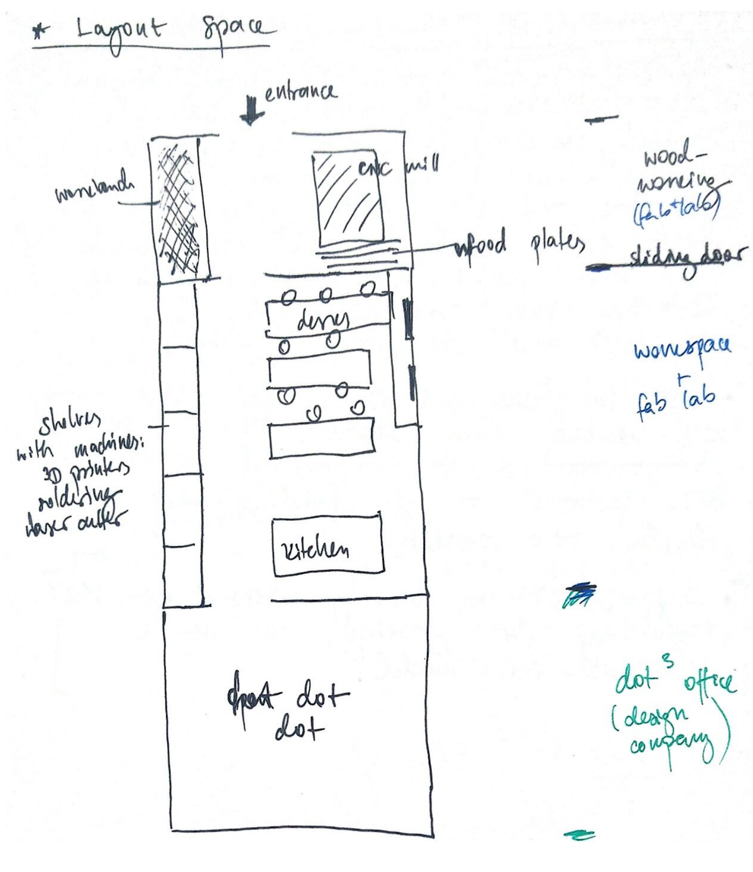

Fig. 5.5. Spatial arrangement of OpenDot (Fieldnotes, September 2016).

[155] See OpenDot's website: http://www.opendotlab.it/.

In the case of OpenDot, the strong ties to professional structures were not something they concealed from their public presentation. In fact, in their homepage description, they acknowledge every individual and company that interacts with them. Other places such as Fab Lab Berlin have been less open about their professional orientation initially. This memo based on my fieldnotes about their Friday public tour, which I attended separately from my dedicated field work at the space, reflects on the relationship to professional structures:

> I am part of a large group of people attending the weekly free tour of a shared machine shop. "We're an 'Open Innovation Space,'" tells the guide and staff member. "Ours is one of the biggest [spaces] in Europe." Size is a popular metric for shared machine shops. Yet, it is a peripheral feature if there aren't the "right" machines and an engaged community. The guide goes on describing the space, the machines, and how it operates. The presentation sounds like for a group of investors at a business trade show, and not for an unacquainted group of people. I wonder how many of them are first-time visitors of a shared machine shop. Wandering through the space from one fabrication area to another, the guide keeps repeating how precise these machines are, whenever we see a different one. I really feel I'm here to invest in a business and not to learn new skills or interact with like-minded people. This deliberate language of high tech innovation and a professional attitude permeates the entire tour. Tinted with colorful furniture and the usual makerspace gadgetry, don't forget the obligatory 3D-printed Yoda head, the veneer of openness and accessibility peels off as we approach the restricted yet very visible co-working area. The fact that the space is tucked between a closed co-working area and a research office of a famous medical supplies company is intriguing. There is no doubt these play a role in this entire arrangement of machines, humans, activities. What and why? (Fieldnotes, October 7, 2016)

While the clarity of the interior provokes an openness expected from a space aligned with the Fab Lab charter, its additional sections blur that. The openness also allows blurring the professional and more commercial activities happening in the background, while the more visible maker community and their practices camouflage that. Interestingly, the effects of that were also blurry for some of the fab lab's staff members. On one of the afternoons I spent there, there was much commotion in the main space area, where most of the members and visitors reside. Some of the other fab lab employees were rearranging and placing chairs, while others were setting up the projection technology. Upon asking the fab lab manager what is supposed to take place, they had no idea and asked one of the others. As it turned out, there were two tours scheduled for the afternoon, but none of them had been posted on the public online calendar of the space. These exclusive tours were booked by and organized for private enterprise groups. Over the time I spent at Fab Lab Berlin, I learned that tours like these happen regularly, and often the site's members learn about them on a very short note. The fact that these require the main working area puts much stress onto the regular members since many of them not only use it for its fabrication technology but as a workspace substitute. In such moments, the options for escape become extremely limited since all other spaces are closed off machine fabrication labs.

The tensions in these situations become multiple. The most apparent one seems the tension between a market-driven and a community-driven objective, which haunts maker cultures in general, but rather pressingly in the places with concealed activities such as corporate partnerships and some form of research and development work that emerges from that. In places like OpenDot where the objective to engage with a broader and less professional community is low, the provision of services such as research and hackathons to business enterprises produces little tension at first place. In a country such as Italy, where design occupies a position equal to art, patronage work is a common form. Nonetheless, all these places draw heavily on the principles of open source and free software movements such as community care and non-profit alternative modes of existence. Therefore, instrumentalizing these principles to establish close alliances with corporate interests should not be taken-for-granted. In a way, these principles and values add to the 'maker infrastructure,' while the tensions arising from their application and their co-optation by neoliberal and capitalistic objectives reveal the breakdown. The breakdown, however, is partial. For a tech-oriented audience labeling an exclusive co-working space as R&D, which operates out of a fab lab, recalls the glorious histories of Silicon Valley's 1960s and 1970s (see Turner, 2006). At the same time, it designates the complex networks of corporate and military influences that destabilize alternative models of work and life. These naming practices also work to situate alternative, often deemed feminine practices likes weaving, knitting, or other less technologized activities, within a gendered context of technology production that disregards their active role in broadening these cultures (Rosner, 2018).

In concluding this section, I return to the notion of hiddenness and how that informed my position as a scholar. That a space is more visible than another is not always a sign of inclusion and acceptance. Often the more openly visible places such as Happylab in Vienna and Berlin suggested inclusivity and friendliness, but also loose connections within the membership. However, governance and rules of a space define these connections too. Hidden spaces, on the other hand, demanded not only my interaction with the makerspaces' founders and core members but also the agreement of the entire community about my participation and study. This situation varied between my primary and ancillary sites. Subjective factors such as their recognition of my knowledge and study of maker cultures and the value of exchange about these topics with them could intervene in my acceptance by particular members thus withholding information about the sites, their practices, and the hidden infrastructures.

For example, when visiting the Copenhagen-based hackerspace Labitat, I was aware of its subversive and underground position, which allowed me to locate it effortlessly in the local area.

However, their underground location and positioning as a hackerspace meant that individual members restricted access and visibility to their activities to me as a researcher and therefore a potential communicator to the public of their undertakings. Hiddenness from the outside operates from the inside as well. At OpenDot, on the contrary, the active participation of several of its members in research and the public representation of maker activities initiated an instant acceptance of my research and then later of my presence. For them, the exchange with an external scholar and acceptance in their space was not in dispute with their ongoing professional activities, as they had developed strategies such as the interior spatial arrangement that protected making some of that transparent. While I argued in this chapter's section that hiddenness and the withholding of external material elements impact the objectives of inclusivity and acceptance behind maker cultures, and thus 'everyone's' participation in them, my subjective position as a researcher also cannot adequately express the perspective and experience of regular members of these communities about these particular infrastructural notions.

Moving Forward Beyond the First Impression

Talking with one of my interlocutors about different shared machine shops and their orientations during dinner, I recall their denigrating response to a space I had just described. "But it's not one of those utopian ones?!", they voiced. The response confused me since their tone was clearly uncomplimentary. Utopian for them meant alternative modes of existence presented by subcultures and counter-cultures yet lacking the promise of capital revenue. However, it also seemed confusing as they had just criticized a different space, we both knew closely, for being "too commercial," that meant putting too much effort in low pricing and a high number of members over cultivating a close-knit community. For Will Holman, an architectural designer and executive director of a Baltimore makerspace, writing in *Places Journal*, this asymmetrical valuation sits upon the roots of making and digital fabrication in technological production:

> Not surprisingly, given its tech lineage, the makerspace community continues to judge itself on the basis of startup metrics: fast expansion, impressive investment, and the appearance of so-called "unicorns"—ideas that blossom into companies worth billions. […] I'd argue that we aren't using the right measurements to gauge their progress. Makerspaces are not simply startup boot camps or factories of the future. To argue that they can succeed merely by existing—build it and innovation will bloom!—is to ignore the multi-faceted nature of making and also the basic value proposition of the spaces themselves. (2015)

In the previous section, I presented how the material infrastructure informs the social structures and even infrastructures of these particular spaces. The critical analysis of these infrastructural aspects suggests a betrayal of maker cultures' underlying values such as community building, skill-sharing, and openness. However, the careful observation of these communities' self-reflection upon problematic aspects indicates what I refer to as a "moving forward," thereby softening the negatives. Instead of outlining an ideal version of maker environments, in this section, I turn to different examples from my field sites that suggest convivial and respectful existing of heterogeneous if not contradictory objectives and individuals. For the philosopher of science Isabelle Stengers, this strategy works to empower "minorities" in the meaning of small, cohesive groups as opposed to the broader understanding connected to political, social, and racial discrimination (1994). She writes: "I dream about multiple connections among minorities, so that each of them will be able to work out its own singularity through the creation of alliances, not in isolation, and so that each individual would be simultaneously part of many minorities" (ibid., p. 41). How can the socials tools of maker communities such as empowerment, encouragement, and exchange apply to other ambitions apart from innovation and professional practice? How can something singular as making and digital fabrication in Stengers' words become part of multiples without being a friction or an assimilatory action? The empirical snapshots that I discuss here present no definitive model. They do not aspire to do that. Instead, they offer alternatives and possibly as Brazilian educator and researcher Felipe Fonseca poses "make room for the unpredictable" (2016). Nonetheless, while Fonseca's analysis is based on the disparities caused through postcolonial power asymmetries, my cases are taken from mostly Western European maker environments and initiatives. These examples, therefore, remain significantly situated in privileged social and technological territories yet appear to counter the uniformity of Western technology cultures.

Alternative communities within maker and hacker cultures are certainly not an exception as their histories illustrate (see Turner, 2006; Coleman, 2013). However, in recent times, they are becoming one with global models such as the fab lab certification by the Fab Foundation or the Fab Cities network. During the entire fieldwork, I maintained an informal relationship through email exchange and occasional meetings at specific events with the FabLabDresden and their overlooking associations #Rosenwerk and Konglomerat. While the fab lab's website has a link to the Fab Charter, it rather works to permit them to use the term 'fab lab,' and also to enable an identification of its function as a shared machine shop to outsiders. Many of its members and the local community might comparably call it Werk.Stadt.Laden, Rosenwerk, or Konglomerat. The entire constellation is based on exchange and collective support in different enterprises. Together they work towards the revival of urban life in a less attractive for cultural activities but very populated neighborhood in the city. At the same time, located in a former industrial zone adjacent to this neighborhood, the fab lab and its other initiatives ensure that the professional practice of some members can be performed on similar terms as the alternative communal activities. In fact, some of their technical infrastructure is provided by the professional members who also take care of their maintenance. The concept works on a time-sharing principle. That means that the professionals have a priority concerning usage while on weekends and evenings the tools are available to others to work with.

Two of their projects, for example, developed with the technical infrastructure on loan by their professional members aim to support the local neighborhood. These initiatives include a relatively easy to build bike-trailer and a plastic garbage recycling system based on the Precious Plastics prototype. While the bike-trailer can be fabricated for personal use, the cooperative aims to encourage sharing the fabrications within the neighborhood. The plastic recycling project engages the community through the reuse of donated materials as locally produced household objects. The cooperative's workshop areas are also modified continuously to offer space for other initiatives and organizations such as a local textile fabrication group or a bike repair collective—both having had lost their facilities due to property issues. While many makerspaces and fab labs tend to define their workshop areas during their foundation and thus restrict them within specific parameters; this initiative scales out by reflecting on the different interests not only of its members but the local population in the urban area too. Indeed, such an organization requires different funding models as well as different metrics to measure success. But it also shows that a mutual coexistence of professional along other objectives becomes attainable.

MAKlab in Glasgow as an independent, charitable organization, followed similar principles. Their motivation from their beginning, and until the closure in 2017, was to bring together different groups of people by acknowledging that everyone's skills and expertise can contribute to these environments. One of their social projects was enabling what they called "age exchange" between often retired engineers and young designers and makers. For them, the former contributed traditional mechanical engineering knowledge, while the latter could offer CAD skills. Encouragement matters as WeMake's co-founder Zoe Romano told me (2016). For her, knowing the interests and skills of their community to encourage them to step up is essential to running a makerspace. Similar to MAKLab, WeMake also engaged in an "age exchange" practice. However, inter-generational projects are often placed on the margins of many Western maker cultures.[156] Meanwhile, the political narrative of reskilling individuals to adapt to the practical changes of digitalization overlooks these existing efforts possibly due to their marginal existence; but also as they seemingly lack the prospect of immediate capital revenue. More likely a pre-work business talk or breakfast gathering at a design studio or tech company would receive external or public financial support to strengthen the skills of this community, rather than allocate it to less profitable undertakings. Similar activities are also offered at professionally oriented makerspace such as Makerversity under the rubric of community-building. The goal, however, aims at solidifying specific standards and norms, not necessarily at enabling exchange.

Community-building events regardless of their motivation, establish necessary social infrastructures. To return to Fonseca's "making room for the unpredictable," I want to summarize in brief my experience from two maker-centric conferences, which I attended back-to-back. The first one took place in Berlin as part of a now concluded research project on commons-based peer production in open labs (Cowerk), run together with the independent German institute IÖW, and focused on the question of maker cultures' potential as a transformative phenomenon.[157] Despite its open goals, the activity was predictable in the outcomes. In the context of transformation, this event included mainly male presenters and topics primarily discussing makers' prospects in terms of innovation and scaling up. Likewise, the majority of the audience consisted of managers and founders of different shared machine shops who were looking for discussions on best practices and the possible development of standards rather than dealing with the marginalized and problematic aspects of maker cultures. Indeed, artist and scholar Chris Csíkszentmihályi's keynote and thesis in reference to Langdon Winner (1977) that the maker movement is not a technology-driven movement but one driven by actors that reproduce the status quo received less appreciation than Fab Lab Barcelona's director Tomas Diez' circular economy presentation.

Expecting somewhat similar discussions on innovation or the potential of local production, two days later at the Maker Assembly in Edinburgh, I encountered the 'unexpected' alternative. The Maker

[156] During my fieldwork I discovered a flourishing alternative initiative supported by the Austrian government. The Otelo Network with its 26 Otelos (Offene Technologielabore, i.e., open technology labs), all in different rural areas, provide a shared space with the only equipment installed being a kitchen. The rest is empty leaving it to the community to determine the spatial design, the needs, the tools, and the activities. The model jokingly called a "Montessori kindergarten for adults" started in 2010, and still keeps opening new spaces. Most importantly, no single Otelo follows external goals from business, economy, politics, or education; instead, it is self-governed and self-determined.

[157] An official report in German only can be retrieved from https://www.cowerk.org/home/single/article/maker-auf-dem-weg-zu-einer-transformativen-bewegung.html.

Assembly was a series of gatherings for people interested in making, craft, and digital fabrication, initially funded by the British Council. As such, it aimed to broaden the conversations around the politics, the history, and the future of these cultures by exchanging and inviting contributors from different cultures outside the borders of the United Kingdom, Europe, and North America. The program booklet stated that "[t]oday is about [...] connecting with fellow practitioners that are like-minded and not-so-like-minded; questioning our worldview by listening to others' that may be lesser known; testing assumptions and hypothesis; and thinking through acts of making with others" (Maker Assembly, 2017). This rhetoric is not novel thus being wary about the prospects seems normal. However, the experience of this one-day event confirmed much of the booklet's description. The organizers structured the day to include as many as possible activities and opportunities for participants to interact and connect with each other. Aware of the difficulty of bringing up strangers in conversation, we—the participants—gathered for different hands-on workshops after the first session of talks to acquaint ourselves with each other. The activities varied from building small synthesizers with Helen Steers' Do It Kits, through workshops on the deconstruction of cultural stereotypes and representations, to a reflective workshop on the materials that surround us through the creation of solid wood joints by melting plastic bottles. In contrast, the hands-on workshops at the Cowerk conference in Berlin focused on group discussion of possible 'solutions' to transform and scale up making.

Beyond workshops and talks, the Maker Assembly provided room for interaction in the breaks and in a final reception that included a traditional and memorable Scottish cèilidh.[158] While the format provides interpretation as the unexpected, I rather consider the content itself as such. Whether it was intentional or not, probably it was, the majority of the speakers and workshop leaders at this gathering were women from culturally and professionally diverse backgrounds. Moreover, the audience gender balance was equal and not something that can be controlled as easily through online registration tools like Eventbrite, which Maker Assembly used in this case. Through their international focus and a recently launched Shenzhen-exchange initiative, the assembly was also attended by makers, technologists, and activists from South Africa, Nigeria, Turkey, and China. But all this seems secondary compared to the following aspect—not a single presentation mentioned the word 'innovation.' Instead, the buzzwords at this event were participation, inclusion, care, and maintenance. As Daniel Charny concluded in his short presentation on the role of making in the twenty-first century, "We

[158] A cèilidh is a traditional Scottish or Irish social gathering which involves folk music and dancing.

need to look at social skills and empathy" (Fieldnotes, March 2, 2017). Engin Ayaz, one of Istanbul's ATÖLYE cofounders invited as the Maker Library Network presenter, emphasized that maker technology and similar new developments should not become the driving goals and motivations if they do not make sense in a specific context. "We shouldn't fall into the trap of thinking that we're doing good; utility is a time function," he added (Fieldnotes, March 2, 2017).

The purpose of the examples I discussed in this section bring to mind historian James C. Scott's argument about recounting alternatives in general, and in his particular case, of mētis (practical knowledge). These function, he writes, "to alert us to the social conditions necessary for the reproduction of comparable practical knowledge" (1998, p. 334). My point is not that the way Fab Lab Dresden or other similar initiatives operate or how the program of Maker Assembly is curated offer specific accounts of practical knowledge. So few examples could never claim to provide an exhaustive account. Instead, I want to highlight through them the contingency on "social conditions," which in other terms functions as social infrastructure, to create multiple, heterogeneous, and inclusive cultures of making and digital fabrication aware by themselves of the tensions and power asymmetries of making's technological legacy.

Conclusion

The materiality of infrastructures exposes their past and present conditions and makes promises for a 'better' future at the same (Howe et al., 2016). Maker cultures and digital fabrication resort to the 'broken infrastructures' of technology production and power asymmetries by promising to democratize access to technologies and their practices. However, this chapter reveals that access should not be taken-for-granted as everyday instances of material and social infrastructures such as invisible entrances and rules of operation work to set limits. Further, by drawing on the theoretical framework of infrastructure as a relational construction with its multiple dimensions, as described by Star and many others, I argued that making as a design practice reproduces conventional standards rather than supports future alternatives. The chapter, in a way, returns to the outlining discussion in *Chapter 2* with the comparison between the Bauhaus's mechanisms of operation and its specific similarities with DIY making and digital fabrication. I do not claim that histories repeat by closing the feedback loop, but that precisely projects touted as new and 'countercultural' are likely to replicate well-established norms and traditions. One final example rearticulates my argument about the reproduction of standards through infrastructures.

In reviewing materials, I had collected during the fieldwork, I rediscovered a small brochure from a recently launched undergraduate program which I took with me from Happylab Vienna. The program titled "Design, Craft, Material Culture" is offered by a private university in Austria, and boldly claims that "The future is not waiting. Fabricate it."[159] The wheel of design education, in this case, was not being reinvented, just repackaged. The tailored curriculum based on a person's prior practical experiences promised best chances on the job market for a moderate tuition fee per term. Additional fees applied if students chose to supplement with craft skills or academic research. The model retrofits the craft studio practice developed at the Bauhaus by "innovating" it through "future-defining" questions such as what is the role of handiwork and craft amid 3D printing. In short, it suggests that the status quo of design education is breaking down rather than being broken, and their model is there to make it future-proof. Instead of weaving in actual alternatives lived by different maker communities which emphasize the values of handiwork, repair, care, and conviviality, as I illustrated earlier, it camouflages innovation-driven fabrication as a form of craft recognition. The brochure also shows what is at stake. As making and digital fabrication keep expanding in order to scale up, their infrastructures—hard and soft—turn back towards the customary order of organization.

[159] The program's brochure is in German. The translation of the program and its slogan are mine.

Chapter 6.
Conclusions and Implications

> Making has to do with the aggregated potential of the material and immaterial worlds.
>
> —Theaster Gates, 2016, p. 42

> Utopia is sometimes the goal. It's often embedded in the moment itself, and it's a hard moment to explain, since it usually involves hardscrabble ways of living, squabbles, and eventually disillusion and factionalism—but also more ethereal things: the discovery of personal and collective power, the realization that is as emotional as it is political, and lives that change and do not revert to older ways even when the glory subsides.
>
> —Rebecca Solnit, 2016, p. xxiii

In this final chapter, I return to the promises of making and digital fabrication, which I introduced at the beginning of the dissertation, to discuss how their rhetoric differs from reality. In doing so, I review the argument and themes of this project and address them through my research findings. I have argued that making and digital fabrication maintain a supportive environment for contemporary design, rather than transforming established practices and systems of design and production, as its proponents suggest. This environment reproduces traditional practices and values, negating much of the countercultural and alternative capacities of maker cultures. As Noble writes, "Social relations and forces of production are thus at the same time in correspondence and in contradiction" (1977, p. xviii). The argument has followed three central themes: (1) the prospect of instantly materializing design through making and digital fabrication, while re-uniting it with manufacturing; (2) the amount of skill and expertise needed for participation in these practices and how these are encoded in rhetoric and practice; and (3) the material and social infrastructures that shape making as a design practice.

I explored these themes by combining a multi-sited ethnographic survey, focused on design practice in shared machine shops, with a critical historical analysis of the relationship between making and design. Ethnographies contextualize cultures, events, and practices from a temporal and spatial distance. "Ethnographers always arrive late," notes social scientist Johan Söderberg (2017, p. 1) in a recent review of publications on hacker practices. The results are often "off-cycle" when the subject of inquiry is "shaped by the hype cycle of new technology" (ibid.). The hype cycle influences the narratives on digital fabrication technologies and practices of making, often by stripping away the historical context that helped produce them. Ethnographies require that we re-construct these contexts and their techno-social interactions if we want to understand how contemporary phenomena acquire meaning. In this conclusion, I summarize the implications of my ethnographic study and the historical reflection in light of the prospects of making as a design practice and what these prospects omit.

In *Chapter 2*, I returned to the historical project of the Bauhaus school with its specific visions of workshop-based design education for the production of mass-manufacturable prototypes and its leveling of the hierarchies between craftspeople and artists. A comparison between the Bauhaus and contemporary maker cultures was based on their common instrumentalization of craft and its embodied practice. Drawing on a discourse analysis of primary sources of some of the leading Bauhaus figures' views on pedagogy, art, craft, technology, and industry, I described the three often acclaimed positions of leveling hierarchies, rejection of specialization, and the workshop vision mentioned above. This historical reconstruction of the Bauhaus model served to demonstrate how maker cultures and digital fabrication borrow a similar narrative on the politics of craft fabrication. Hence, I contrasted three contemporary cases from my fieldwork with the historical insights. The first, a vignette from a recent exhibition on contemporary and historical craft at the Bauhaus Dessau, which included projects developed following DIY principles and digital fabrication, exemplified how the latter are finding their ways into professional design. The second example investigated the motivations behind students' participation in makerspace activities to explore how this participation happens as part of higher education in design disciplines. Finally, the third example discussed the workflows and development strategies of two maker businesses to show how they follow a model similar to the Bauhaus paradigm of workshop production. The practical examples helped challenge the prospects of maker cultures and digital fabrication as enabling re-industrialization and the deprofessionalization of design or manufacturing. Further, in following Noble (1977), the comparative analysis aimed to emphasize that claims for radical changes require historical reflection.

The idea of re-industrialization reappeared in *Chapter 3*, where I interrogated the opportunity presented by making and digital fabrication to materialize design and to further unite it with manufacturing. The initial theorizing in the history of design and technology suggests that these propositions originate in a long-standing division between design and manufacturing and a broader perception of design as an immaterial and conceptual practice. Making and digital fabrication imply a unity on a personal level by empowering users, in particular, designers to access industrial means of production, on a technological level based on automated technologies and processes of CAD/CAM, and on a geographical one that evokes the revival of urban manufacturing. Often described as a paradigm shift in design, I argued that these recent practices and technologies propose associations between design and production. On one side, they provide expected connections. I illustrated this through interview material and participant observations in two themes: a comprehension of the proximity to production and its values for making and design; and three different levels of urban manufacturing revival. On the other, I discussed that connections also include probable disconnections. An analysis of the technical complexities of learning digital fabrication workflows as well as the growth of digital fabrication services hinted that the idea of "wholeness" behind the CAD/CAM workflow is difficult to achieve. Moreover, I illustrated how the disconnected focus on CAD or CAM in machine shop training signals a prerequisite of skill and expertise, precisely because the links between them remain incomplete.

Skill and expertise were the focus of *Chapter 4*. There, I questioned why making and digital fabrication seem preoccupied with a notion of non-expertise as both entry point and condition for 'success.' I argued that maker cultures paradoxically blend perceptions of access and effortless acquisition of skills with a demonstration of advanced technical projects legitimating its expert status. I illustrated these contradictions briefly through a review of critical scholarship in the social sciences, craft research, design studies, and human-computer interaction on different forms of skill and expertise. This scholarship informed the analysis of online material and fieldwork data from interviews, observations, as well as autoethnographic accounts. While online data and interviews described how practitioners present knowledge and talk about machines and processes, my experience in learning CNC milling over four different training activities helped me approach the experience of a novice directly. The data revealed that expertise by making, like other distinctive forms of expertise, depends on a local and situational context to validate itself as such. By referring to authorized sites of knowledge and skill and implementing them as credential systems for expertise, maker cultures reinforce their own 'ecology of expertise.' Further, to trouble the norms and the public rhetoric around expertise for making, I challenged the framing of makers as 'everyone' in a discussion on gendered traditions of expertise and their codification in technical practices. Therefore, I proposed that maker cultures and their cultivated environment start eliminating an apparent openness and instead come up with more accurate depictions of their user groups and objectives.

Ultimately, in *Chapter 5*, I examined the infrastructural effects of making and digital fabrication on their emancipatory visions. In reading mundane elements of maker environments such as entrances, signage, and the spatial organization through infrastructural studies, I argued that these elements reproduce conventional norms of work and power hierarchies rather than present a potential alternative to established modes of design and production. Through fieldwork snapshots such as stories of finding particular makerspaces or the analysis of their interior and exterior visual appearance and spatial organization, I looked at how infrastructures as methods of classification selectively include and exclude. At the same time, this chapter aims to illustrate how different activities happening around my field sites work to break the cycle of reestablishing customary norms and categories.

Concealments of Making as a Design Practice: Broader Implications

What makes making and digital fabrication so enticing? Reviewing the fieldwork data and reconnecting it with my personal experience, I come to the conclusion that maker cultures' enticement lives in what it actually conceals. At the Maker Assembly in Edinburgh, Daniel Charny concluded the panel and discussion on the role of making for the 21st century saying that "there's a fear that discussions on making hide other issues such as rebranding" (Fieldnotes, March 2, 2017). In following his argument in this closing section, I want to connect my research findings to current and future developments in maker cultures to underline what becomes concealed and to propose alternatives. Each example of a specific current or future prospect for making is juxtaposed with critical observations from my fieldwork and their implications. In addition, I discuss how these examples connect to the themes of the dissertation.

One vision of the current maker cultures is the manifestation as redistributed manufacturing. Originating at the MIT, the Fab Foundation brought forth the fab lab model. It distributed this franchise model across the globe by creating a manifesto-like charter and providing guidelines to interested applicants for opening their own spaces. As the fab lab network grew, the model helped establish a system for redistributed manufacturing, the Fab Cities Network.[160] Based on the virtues of the sharing economy and peer-to-peer networking, the cities and regions participating in the Fab Cities network vouch to improve the traditional system of manufacturing with its long supply chains, offshore production, and dreadful impact on the environment. Framed around resilience, local production, and environmental sustainability, the proposition for improvement follows the idea of trading digital files such as designs, blueprints, manuals, while sourcing out materials and manufacturers in the immediate local surrounding. As a result of this endeavor, production of goods will become limited and customized to local needs. The underlying idea is hardly novel, although the maker cultures, their communities and technologies, maybe. In fact, Fab Cities draws on the concept

[160] The Fab Lab Network currently counts 1,299 fab labs across the world according to its online database fablabs.io (last accessed: July 22, 2018).

of the circular economy from the late 1970s.[161] Both, Fab Cities network and the circular economy, also rely on the characteristics of a modern and post-industrial society described by sociologist Daniel Bell (1973). For Bell, the modern, post-industrial society is defined by an increasing professionalization and the central role of technical knowledge as related to computer systems. This is what makes models like the Fab Cities model problematic—they emphasize specialized and professional knowledge while actually relying upon less-valued manual labor and products.

The Fab Cities is perhaps attainable if the neighborhood networks of shared machine shops in urban areas become dense enough. Yet materials like wood for milling or laser cutting, synthetics for 3D printing, and required electronic components don't grow in the cities. The Fab Cities likely acquire the materials from local vendors, but the materials' origin is non-local. In other instances, where the material might be local, the necessary manual labor is missing. These aspects, however, tend to be concealed in the rhetoric of Fab Cities, redistributed manufacturing, and maker cultures. However, as researchers of emerging technological trends and developments, we ought to understand and explore in detail what, for example, the maker narrative and the dominance of a few maker organizations conceal about the real image of manufacturing. As Shenzhen-based hacker and makerspace owner David Li suggested at the Maker Assembly, maker cultures advertise a Renaissance of manufacturing ideas in developed countries by hiding labor issues in developing countries. In *Chapter 2*, I illustrated through Animaro and Kniterate that makerspaces provide the means for prototyping, while the actual manufacturing happens elsewhere—in Kniterate's case in China. In fact, these two are not unique in their practice; rather they represent the norm across design practiced in makerspaces. In many ways, while designers are empowered to manufacture, they lack the experience and the precision that comes with traditional chains of production. I bring up the example of Fab Cities to elucidate what making conceals through rhetoric: How is locality in terms of materials and processes defined? Who produces? And who is the beneficiary of this model?

The rhetoric around these models is usually silent or vague on issues of class. A recent interview with urbanist Thomas Ermacora at the annual Fab Foundation meeting (FAB14), however, disclosed the importance of the category. Asked about the role of fab cities and how maker cultures contribute to that, he explains:

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[161] Recently, the circular economy model has been associated with economic models by the Ellen MacArthur Foundation, an independent charity organization.

> One of the opportunities of the maker movement, in association with cities, is to bring industries closer to inhabitants' needs, to be able to produce customized goods with local materials. The second reason is that there is a tremendous opportunity gap that needs to be addressed by cities in terms of capturing talent. Talent is the most expensive currency to any organization, city, government, nation. It is the hardest thing to form and the hardest thing to keep. One of the beautiful things with makers is that it's a very self-learning and adaptive intelligentsia. It's a new class of people. (2018)

His answer invokes a binary. There are the cities' residents, on one side, and then, there are the "new class of people"—the makers, on the other. Ermacora does not propose how to connect them. Instead, he reproduces a new creative class definition of another well-known urbanist, namely Richard Florida (2002). Florida's conception of the creative class has come under criticism for 'whitewashing' the effects of his described new economy on the working class. At this moment, ideas like the Fab Cities model or redistributed manufacturing are probably less threatening to our social conditions than the undertakings of global Internet corporations in the physical world. The problem comes when such ideas reproduce the power of already privileged groups like designers and engineers on the account of technosolutionism camouflaged as goodwill and sustainability. Further, such ideas propose that making and digital fabrication become sanitized "with politics, activism, tactics, history, economics and social issues removed in the process" (Hertz, 2012).

Making's prospect of blurring identity boundaries by making objects remains the most contentious one in my opinion. Like re-industrialization, this sort of "deprofessionalization" is imbued with Western conceptions of class and order. Its translation into ideas of wholeness and unity reflects gestures of power that are concealed as the histories of CAD and CAM demonstrate. Instead of calling for a blurring of identities or uniting to empower the under-privileged, the discussions should turn their focus towards the current identity hybrids often marginalized by the popular accounts of innovation and invention. Meeting with several Chinese makers from the area of Shenzhen during the Maker Assembly in Edinburgh and listening to their critical comments on the Western idea of making changed my perspective on this particular proposition of maker culture. While presenters, mostly from the global north, expressed enthusiasm about the potential empowerment by seizing the means of production, these Chinese makers questioned the dualistic cultures of design and production. As David Li explained while watching others participate in the Scottish ceilidh dancing, in China everyone traditionally makes different things simultaneously, and Shenzhen's past allows for the dissolution of clear-cut professional definitions.

In the ongoing scholarly discourses around the expansion of design participation, I propose examining the virtues of these hybrid identities that are defined by the blurring of previous ones. Such research pursuit highlights the importance of marginalized communities and practices by giving voice to "those who design without a formal title" (Campbell, 2017, p. 30). Moreover, in studying the notion of expertise and its translation into gender limitation, I indicated another area of concern that requires more attention. These are allied questions that fall outside the scope of this dissertation, but they open up avenues for new research. Like those questions, this dissertation has aimed to critically examine how the practices, people, and infrastructures of making might begin to align more closely with their hopeful promise. Attending to the current and continuously reframed 'revolutionary' narratives around making and digital fabrication, this project discussed how their critical elements—skill, expertise, social and technical infrastructures—construct broader participation and future development of this phenomenon. As such, the dissertation gains relevance by questioning how the status quo of design and technology production is maintained rather than subverted as maker cultures promise. This challenge required contextualizing these recent technological developments and social projects historically to critically examine some of their emancipatory ideals. The connection I made in the dissertation between these general and therefore camouflaged promises of maker cultures with the particular social, cultural, and economic backgrounds of my field sites' urban locations bears significance for future and more specific research avenues on maker cultures' transformation as something independent and alternative to the norms, or as a co-opted instrument. Specific questions could address the proposals and consequences of the reasonably recent idea of maker cultures and the Fab Cities as the future of urban smartification; the ongoing and strengthened alliances between technology corporations, government, education, and military institutions; or the correlation of makerspaces to art and design schools and capital.

More importantly, this dissertation, the questions it asked, answered, and opened up for future avenues, matter not only for social research on technological prospects based on a concrete example, namely makerspaces, but for illustrating how this concrete example becomes an occasion for larger subjects of discussion. While scholarship and probably the measured economic impact of maker cultures speak for the phenomenon's marginal existence, my research demonstrated that that the perceived 'marginality' of making, maker cultures, and digital fabrication allows these ideas to thrive invisibly, while the veneer says something very different about the contributions of this technoculture.

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