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Manuel Moritz · Tobias Redlich
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# Global collaboration, local production

## Fab City als Modell für Kreislaufwirtschaft und nachhaltige Entwicklung



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# SDG – Forschung, Konzepte, Lösungsansätze zur Nachhaltigkeit

Die nachhaltige Entwicklung unserer Welt ist eine der wichtigsten Herausforderungen in Gegenwart und Zukunft und zugleich eine Aufgabe, an der alle Wissenschaften beteiligt sind. Um einen sichtbaren Beitrag auf diesem Weg zu leisten, gibt SPRINGERNATURE die Buchreihe SDG – Forschung, Konzepte, Lösungsansätze zur Nachhaltigkeit heraus, in der Arbeiten aus allen Disziplinen publiziert werden können, die die wissenschaftliche Analyse oder die praktische Förderung von Nachhaltigkeit zum Ziel haben, wie sie insbesondere in den Nachhaltigkeitszielen der Vereinten Nationen definiert sind.

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# Preface

Multiple (global) crises in recent years have highlighted the importance of a global approach towards these urgent challenges. The United Nations 2030 Agenda for Sustainable Development and its operationalization by means of the Sustainable Development Goals (SDGs) serves as an important framework for addressing these. The global Fab City initiative and its goal to produce as much as possible locally while collaborating on a global basis at the same time relates very well to some SDGs, thus contributing to reaching them.

Lately, two large research projects were initiated in the Fab City Hamburg. The dtec.bw project Fab City focuses on the development of and research on physical infrastructure, meaning open labs and open-source machines to operate those and its social/economic embedding in the local context. This is an important step towards understanding how local and distributed production might work. One aspect is missing though: a link to other Fab Cities in the digital sphere. Only when other communities have access to shared knowledge and designs, collaboration on a global scale is possible. The EU EFRE-funded project INTERFACER aimed to do just that. We developed and piloted a digital infrastructure, enabling collaboration in ideation, design, and product development. The platform entails innovative features such as a digital design and product passport or an economic model based on contribution and collaboration, fostering value creation both on a local and a global level.

During the projects, we learned that technology is only one part of the equation. Technologies might set the basis, but there are challenges ahead that touch upon other areas such as social, cultural, political, or legal aspects. In fact, there are many open issues that require a joint and interdisciplinary effort from researchers, practitioners, and policymakers.

With this book, we want to give an overview of preliminary findings, potential solutions, and open questions in the context of Fab City, while also invite the research community to pick up on some of the topics. Together, we can turn the Fab City vision into reality.

Hamburg, Germany

Manuel Moritz
Tobias Redlich
Sonja Buxbaum-Conradi
Jens Wulfsberg

# Foreword by Prof. Neil Gershenfeld

In 2015, at the launch of the Sustainable Development Goals (SDGs) at the United Nations in New York, there was an odd sight – a lab. Working with the UN's Non-Governmental Liaison Service, we brought a Fab Lab to the headquarters. The assembled diplomats were perplexed (if not irritated) by this intrusion: they had gathered to tackle the world's greatest challenges, not see machines that make things. Yet, as we talked, they came to appreciate that nearly all SDGs require access to the means to measure and modify the world. Improving health, energy, environment, economy, education … – all require an ability to think globally while fabricating locally.

Around the same time the SDGs were being developed, another initiative was started in Barcelona at the annual gathering of the Fab Lab network in 2014: the launch of the Fab City movement. This linked Barcelona's design legacy with its urgent issues in youth unemployment and the integration of immigrant communities, by providing access to the means to make it a part of urban infrastructure. It was embodied in the start of a 40-year countdown to urban self-sufficiency, turning consumption into creation.

Since then, the Fab Lab network has grown to over 2,500 sites in 125 countries, and there are 49 cities and regions in the Fab City network (as of 2023). Smart cities have been a popular trend in urban planning, but you can't eat data. Fab Cities fulfill the promise of both Fab Labs and smart cities, by turning data into food, energy, clothing, shelter, and all of the other things a city needs. Led by hubs that have emerged such as Hamburg, there are compelling examples of the sustainable local production of each of these. One of the most striking implications and unexpected impacts has been to help reverse urbanization. For many years the growth of cities has been an inexorable trend, with cities acting as regional magnets and engines; the resources enabling a Fab City can also help expand opportunity beyond cities.

The first generation of Fab Labs were needed to provide access to tools. Fab labs are now making a transition to a second stage: rapid-prototyping of rapid-prototyping. Instead of going to a lab to *use* a machine to make something, it's becoming possible to go to a lab to make a machine that makes something. Along with bringing the associated skills and jobs locally, it allows the machines to be as expressive as the projects produced on them, adapting to local needs. To support this transition a network of super Fab Labs is emerging, with more advanced tools to produce the components for lower-cost regional networks.

The fab 2.0 transition is being driven by Fab City demands: creating the capacity to make aquaponic systems, wind turbines, custom furniture, etc. This is leading to what could be described as a 'talking dog moment.' Initially, the mere fact of a dog being able to talk is notable, but eventually it matters what the dog says. Likewise, initially just being able to produce (almost) anything within a city was notable, but what matters now is how well it is made. Food can be grown, but what are the resource requirements relative to traditional farming? How far can it be scaled? What are the consequences for existing supply chains? Who benefits?

It turns out that most cities don't have the data to evaluate their progress on the 40-year countdown, with little insight into the net fluxes of bits and atoms in and out of them. And it turns out that most rapid-prototyping projects don't have the data to evaluate their potential impact on these fluxes. There is now an opportunity and need for labs that can develop, deploy, and measure the frontiers of Fab City technologies. This book provides a much-needed snapshot of the current state of that challenge.

Prof. Neil Gershenfeld

Director of MIT's Center for Bits and Atoms

Chairman of the board of The Fab Foundation

# Foreword by Tomas Diez

The Fab City project was first launched in FAB7 Lima, Peru in 2011. It has grown into a global initiative closely aligned with the principles of (open source) distributed design and manufacturing. Throughout the years, the project has achieved significant milestones in various cities, such as launching the PITO-to-Dido challenge in Barcelona in 2014. In 2016, the Fab City White Paper was published, and the Fab City Campus took place in Amsterdam during the Dutch Presidency of the European Union. In 2018, in partnership with the Fab City Grand Paris Association, the Mayor of Paris, and the European Research, Science and Innovation Council, the Fab City Summit and the second iteration of the Fab City Campus were organized along with the launch of the Fab City Manifesto. In 2020, the Fab City Foundation was established in Estonia, and the Full Stack framework was introduced to tackle challenges and coordinate local efforts. During the same year, and despite the pandemic, the Fab City Summit was held online with offline events in Montreal, Canada. In 2022, the Fab City Summit and the main Fab Lab event occurred in Bali, Indonesia. This culminated in the Bali Fab Fest, the first large event for the Fab community after COVID-19. In 2023, the launch of the Fab City OS in Hamburg marks another significant milestone for the Fab City Global Initiative. This is in its pursuit to develop a global collaboration infrastructure.

Fab City has been developed over the years thanks to strong collaborations between dozens of organizations and hundreds of people. Now with 49 member cities and over 2500 Fab Labs spread around the globe, it is time to rethink how to scale up localized production, digital fabrication, and innovative design practices, as well as the impact of these efforts on urban communities. It is of particular importance to note the Fab City Foundation's commitment to the collaborative development of a common framework to guide these efforts. The Full Stack framework unifies the diverse range of projects and initiatives within the Fab City ecosystem. With such various elements forming the foundation of Fab City, such as the establishment of Fab Labs and creative spaces, which can enable communities to harness digital fabrication tools and reduce their reliance on global supply chains, it is imperative to highlight the importance of collaboration among local stakeholders in fostering a culture of creativity and problem-solving, essential for addressing complex urban challenges.

Moreover, the sustainability and resource efficiency aspects of the Fab City initiative, including the use of local materials, the adoption of circular economy principles, and the reduction of environmental impact through localized production, are fundamental for the introduction of new technological advancements in cities and regions. By sharing these practices with the Global South, the Foundation aims to create new learning environments, with the Full Stack framework playing a key role in guiding these efforts. As we look to the future, a skilled workforce remains crucial for driving innovation and supporting local industries. Fab City's investment in education and training programs emphasizes the importance of a well-trained workforce for sustainable (and regenerative) economic growth. In line with its commitment to inclusivity, the Foundation seeks to provide opportunities for education and skill development in underprivileged regions to help close the global innovation gap and to reinvent the metrics to measure the success of such efforts.

As you embark on this journey through the pages of this book, you will discover the transformative power of the Fab City initiative and its potential to reshape our urban environments. This book is an invitation for large-scale collaborations to build a distributed system that can support the development of alternative modes of production, in line with the social and ecological needs of our time.

Tomas Diez
Executive Director of the Fab City Foundation

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# Inhaltsverzeichnis

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# Einführung: Wie Fab Cities zu einer nachhaltigen Entwicklung beitragen

1

Manuel Moritz, Tobias Redlich und Sonja Buxbaum-Conradi

## 1.1 Warum wir Fab Cities brauchen

Wir erleben derzeit, wie multiple Krisen unsere weltweit verteilten Produktionsprozesse und (ökonomisch) hocheffizienten und globalisierten Lieferketten ins Schwanken bringen können bzw. wie diese aus politischen, ökonomischen oder ökologischen Gründen in Frage gestellt werden (Chopra & Sodhi, 2014). Eine Rückverlagerung von Produktionskapazitäten in Heimatmärkte (*reshoring*) (Ashby, 2016) wird dabei als möglicher Lösungsansatz genauso diskutiert wie die möglichst umfassende Nutzung lokaler Ressourcen durch (lokale) zirkuläre Stoffkreisläufe im Sinne einer Kreislaufwirtschaft (*circular economy*) (Camilleri, 2018). Hierfür müssen Produkte von Grund auf neu gedacht und gestaltet werden hinsichtlich Materialauswahl, Langlebigkeit und Reparatur- bzw. Recyclingfähigkeit (Shahbazi & Jönbrink, 2020; Vezzoli & Manzini, 2008).

Jedoch fehlt an vielen Stellen nach wie vor das Verständnis bzw. die Bereitschaft, die Transformation zu einer nachhaltigen Gesellschaft ernsthaft anzugehen. Von einer kreislauffähigen Wirtschaft sind wir weit entfernt (Grafström & Aasma, 2021). Der Art und Weise, wie wir konsumieren, kommt hierbei eine Schlüsselrolle zu (Godfrey et al., 2022; Terzioğlu, 2021). Zu oft entscheiden wir uns bei physischen Produkten kurzsichtig und bequem für die preisgünstige off-the-shelf-Variante (in der Regel günstige Massenware aus Fernost), die wir schnell nach Hause geliefert bekommen können. Diese Produkte werden ebenso schnell wieder entsorgt mit den entsprechenden Folgen für die Umwelt, weil sie

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etwa technisch veraltet oder defekt und somit unbrauchbar sind. Eine Reparatur oder ein Update sind in der Regel technisch weder vorgesehen noch wirtschaftlich durchführbar (Svensson-Hoglund et al., 2021).

Hinzu kommt fehlendes technisches Verständnis und Wissen, um theoretisch und praktisch eine Reparatur vornehmen zu wollen bzw. zu können, was die Folge einer zunehmenden Entfremdung von Produktion und Technik ist (Hernandez et al., 2020). Insbesondere junge Menschen sind jenseits der Nutzung von Gadgets immer schwerer für Technik zu begeistern (Young et al., 2002). Dies ist einer der Gründe für einen massiven Fachkräfte- und Nachwuchsmangel in Handwerk und technischen Ausbildungs- und Studiengängen (Dietrich & Severing, 2007). Innovative Ansätze im Bereich der MINT-(Aus)Bildung z. B. im Bereich digitaler Produktionstechnologien sind die Ausnahme.

Dabei war es nie einfacher, günstiger und leichter, selbst produktiv tätig zu werden bzw. dies zu erlernen. Wir beobachten eine zunehmende **Demokratisierung von Produktion**, die weltweite **Verbreitung von offenem Wissen** in diesem Bereich (durch Open Educational Resources, Open Source Software und Hardware) sowie **kollaborative Produktentwicklung** auf globaler Ebene auf themenspezifischen Plattformen und in Online-Communities. (Basmer et al., 2015; Redlich & Moritz, 2016)

Der Desktop-3D-Druck ist dabei nicht nur ein sehr gutes Beispiel für eine mittlerweile weit verbreitete, niedrigschwellige und kostengünstige digitale Produktionstechnologie. Vielmehr ist die Entwicklung der Technologie selbst beispielgebend für einen nicht gesteuerten, kollaborativen und Bottom-up-Innovationsprozess, indem ausgehend vom RepRap-Projekt knapp zwei Jahrzehnte tausende Menschen weltweit gemeinsam zur Entwicklung bzw. Weiterentwicklung beigetragen haben. Voraussetzung hierfür war der Open Source-Ansatz, d. h. die Veröffentlichung der vollständigen Dokumentation des Projekts unter freier Lizenz, sodass jeder das Projekt einsehen, studieren, nachbauen und weiterentwickeln konnte. Auch die kommerzielle Verwertung war bzw. ist erlaubt, sodass sich viele der heute am Markt aktiven Unternehmen, die Desktop-3D-Drucker in verschiedensten Varianten herstellen und vertreiben, gründen und etablieren konnten.In ähnlicher Weise vollziehen sich Entwicklungen in anderen Technologiebereichen, z. B. Robotik, IoT, CNC-gesteuerte Fräsen und Laserschneider. (Arnott, 2008)

Auch ohne Vorkenntnisse können Menschen die Nutzung dieser Technologien durch frei zugängliche Tutorials, Videos oder andere Open Education Resources (OER) erlernen (Halverson & Sheridan, 2014). Es gibt zahlreiche Design-Repositories, wo meist kostenfrei bereits fertige Designs, Schaltpläne und Aufbauanleitungen heruntergeladen und somit die entsprechenden Produkte selbst hergestellt werden können. Auch für die Gestaltung und Erstellung von Produktdesigns stehen kostenfreie und teils quelloffene (Open Source) Softwareanwendungen zur Verfügung. In unzähligen Online-Communities tauschen sich gleichgesinnte Tüftler (sog. *maker*) zu technischen Themen und Projekten aus und arbeiten gemeinsam an Produktentwicklungen.

Die zur Herstellung benötigten (digitalen) Produktionsmaschinen sind vergleichsweise günstig und somit auch für die private Nutzung erschwinglich. Der **Zugang zu den Technologien** und dem Wissen, diese zu bedienen, wird jedoch auch in offenen Werkstätten (Makerspaces, Fab Labs etc.) ermöglicht (Osunyomi et al., 2016). Weltweit gibt es mehr als 1500 solcher Orte in über 90 Ländern (Tendenz steigend), in denen Menschen Dinge herstellen können. Der Maschinenpark umfasst dabei meist eine große Bandbreite an Technologien (u. a. 3D-Druck, Elektronik, Laser Cutter, CNC-Fräsen), wodurch jeder theoretisch in die Lage versetzt wird, (fast) alles herzustellen oder herstellen zu lassen, Produkte zu reparieren, anzupassen oder gemeinsam mit anderen Menschen an neuen Ideen zu tüfteln. Folglich sind Fab Labs sind nicht nur Orte für Produktion, sie sind Orte des Austauschs, des gemeinsamen Lernens und Innovierens (Rayna & Striukova, 2021). Insbesondere Fab Labs stehen dabei für offene, communityorientierte Orte, die vor Ort eine Community pflegen und zugleich in die globale Makerszene eingebettet sind. (Buxbaum-Conradi et al., 2018)

Aus dieser Bewegung heraus hat sich die Fab City-Initiative gegründet. Städte und Regionen, in denen eine starke Maker-Community in Fab Labs aktiv ist, haben sich mit Unterstützung lokaler Akteure zu einem weltweiten Netzwerk zusammengeschlossen mit dem Ziel, in der Zukunft möglichst viel lokal zu produzieren und zugleich global in der digitalen Sphäre zusammenzuarbeiten. Maker-Communities, Fab Labs und Fab Cities können insofern bei der Bewältigung der oben genannten Herausforderungen und auf dem Weg zu einer nachhaltigen Produktions- und Konsumptionsweise einen wertvollen Beitrag leisten (Rumpala, 2023). Sie bilden ein offenes, verteiltes Wertschöpfungssystem, das weltweit Partizipation an Produktionsprozessen ermöglicht, Selbstbefähigung fördert und Bewusstsein für Produktion schafft. (Redlich et al., 2009)

## 1.2 Wie Fab Cities eine nachhaltige Entwicklung fördern

Die Notwendigkeit, globalisierte Wertschöpfungs- und Produktionssysteme (zumindest in bestimmten Teilbereichen) neu zu organisieren und weltweit nachhaltige Produktionsprozesse zu etablieren, ist Ausgangspunkt für die Forschung zu Fab Cities.

Der Fab City-Ansatz beschreibt, wie Produktions- und Konsumweisen gestaltet werden können, damit einerseits eine weltweite Zusammenarbeit in der digitalen Sphäre in und durch Communities von der Ideenfindung bis zur Produktentwicklung physischer Güter unter Nutzung von Open-Source-Technologien (Open Source Software und Hardware) ermöglicht wird; andererseits soll die Produktion dieser physischen Güter lokal möglichst bedarfsnah und dezentral im Sinne einer verteilten Produktion erfolgen, beispielsweise in Fab Labs, Makerspaces und lokalen produzierenden Unternehmen.

Ziel des Konzepts ist es, eine möglichst **nachhaltige Produktion und Wertschöpfung** zu schaffen: **ökologisch nachhaltig** durch die Vermeidung langer Transportwege und die Schließung lokaler Stoffkreisläufe nach Prinzipien der Kreislaufwirtschaft; **wirtschaftlich nachhaltig** durch die Vermeidung von künstlichen Wettbewerbsbeschränkungen durch Open-Source-Technologien und Abhängigkeiten durch föderierte Ansätze; **sozial nachhaltig** durch ein partizipatives Wertschöpfungssystem, in dem der Zugang zu Wissen und Know-how sowie zu Produktionsmitteln uneingeschränkt ist. (Evans et al., 2017; Brandl & Hildebrandt, 2013)

Das Fab City-Konzept bietet einen vielversprechenden Weg zu einer widerstandsfähigeren und ökologischeren Produktions- und Konsumptionsweise (Hildebrandt et al., 2022). Global vernetzte Städte und Regionen tauschen Daten, Informationen und Know-how aus und arbeiten gemeinsam an der Entwicklung physischer Güter in Form von Open-Source-Hardware, während die Erstellung, Reparatur und das Recycling dieser physischen Güter und Artefakte in der lokalen Sphäre erfolgt (Fab City, 2016). Insofern können global vernetzte und lokal produktive Fab Cities einen Beitrag zur Transformation hin zu einer nachhaltigen Gesellschaft leisten und ganz konkret auch zur Erreichung der Sustainable Development Goals der UN beitragen, wie nachfolgend ausgeführt wird (Sachs et al., 2019):

**SDG 4: Hochwertige Bildung** Freies Wissen und Open Source Hardware (in Form von vollständigen Dokumentationen zu Hardware-Projekten) bilden die Grundlage für einen globalen Austausch und kollaborative Produktentwicklung in Fab Cities. Eine Vielzahl kostenfreier und niedrigschwelliger Online-Lernangebote in Verbindung mit Open Source Software ermöglichen eine Selbstbefähigung im Bereich digitaler Produktionstechnologien, Produktgestaltung und Programmierung.

Viele Fab Labs bieten darüber hinaus vor Ort Workshops zu unterschiedlichen Themen an, von Einführungskursen zu Produktgestaltung und Produktionstechnologien über projektbasierte Formate bis hin zu sog. Build Workshops, in denen bestehende Open Source Hardware-Projekte unter Anleitung nachgebaut werden.

**SDG 8: Menschenwürdige Arbeit und Wirtschaftswachstum** Die Offenheit sowohl der Artefakte (Open Source Software/Hardware), der Wertschöpfungsprozesse (z. B. Build Workshops) sowie der Wertschöpfungssystemstruktur (Fab Labs und Open Source-Werkzeugmaschinen) ermöglichen grundsätzlich die Partizipation an globaler und/oder lokaler Wertschöpfung. Zahlreiche wirtschaftliche Möglichkeiten ergeben sich hierdurch von der Bereitstellung und Durchführung von Lernangeboten, über Design, Herstellung, Wartung und Reparatur von individualisierten Produkten für andere bis hin zur Beratung von Unternehmen.

**SDG 9: Industrie, Innovation und Infrastruktur** Fab Labs und Open Source-Werkzeugmaschinen bilden eine öffentlich zugängliche technische Infrastruktur für Produktion und Innovation. Open Source Software und Hardware im Allgemeinen bieten einen Nährboden für Innovation, indem auf dem Wissen anderer aufgebaut werden kann. Vorhandene Software und Hardware kann (Dokumentation) und darf (Lizenzrechte) weiterentwickelt, angepasst und kommerzialisiert werden.

**SDG 11: Nachhaltige Städte und Gemeinden** Das Fab City-Konzept zielt insgesamt strategisch auf ökologisch, ökonomisch und sozial nachhaltige (und möglichst resiliente) Städte ab. Lokale Communities werden gestärkt durch den Zugang zu Wissen und technologischer Infrastruktur in Fab Labs.

**SDG 12: Nachhaltiger Konsum und Produktion** Die Auseinandersetzung mit Technologie und Produktion in Fab Labs und die dadurch erlangte Befähigung zu Reparatur, Gestaltung und Produktion kann einen Beitrag dazu leisten, dass Menschen ihr Konsumptionsverhalten dahingehend anpassen, Produkte zu reparieren, statt wegzuwerfen, eigene Produkte zur Lösung individueller Probleme zu kreieren oder aber Ressourcen und Komponenten für andere Produkte wiederzuverwenden oder aufzuwerten.

**SDG 17: Partnerschaften zur Erreichung der Ziele** Das Fab City-Konzept beruht auf dem Grundgedanken der globalen Kollaboration zwischen Städten und Regionen, um gemeinsam die teilweise ähnlich gelagerten Problemstellungen anzugehen. Der partnerschaftliche Austausch von Wissen, Erfahrungen und Lösungen in der digitalen Sphäre ist hierfür die Grundlage.

## 1.3 Was man zu Fab Cities wissen muss

Das vorliegende Werk liefert aktuelle interdisziplinäre Forschungseinblicke zum Fab City-Konzept und soll die Bandbreite möglicher bzw. relevanter Themenbereiche aufzeigen, die für ein umfassendes Verständnis dieses vielschichtigen Konzepts als Grundlage für die Gestaltung einer auf lokale Produktion und globale Kollaboration ausgerichteten Wertschöpfung notwendig sind.

Es ist zugleich als Einladung an interdisziplinär Forschende zu verstehen, sich ausgehend von den hiernach vorgestellten Themen ebenfalls mit den vielschichtigen Fragestellungen des Fab City-Konzepts zu beschäftigen.

Die Erkenntnisse dieses Buchs sind im Wesentlichen im Rahmen von zwei Forschungsprojekten entstanden. Das EU-EFRE geförderte Projekt INTERFACER zielte übergeordnet auf den Aufbau, das Testen und die Validierung einer quelloffenen digitalen Infrastruktur in Form eines föderierten Netzwerks zum Aufbau und Betrieb eines lokalen und dennoch global vernetzten Wertschöpfungssystems ab. Entlang des Konzepts der Commons-basierten Peer-Produktion und über den gesamten Produktlebenszyklus hinweg soll das sogenannte Fab City OS (OS = Operating System) Städte und Regionen in die Lage versetzen, Daten, Informationen und Wissen, die in globalen Netzwerken generiert werden, zu bündeln, zu systematisieren und zu teilen Praxisgemeinschaften, um physische Artefakte lokal verteilt, nachhaltig und belastbar zu produzieren.

Das EU-geförderte dtec.bw-Projekt „Fab City – Dezentrale digitale Produktion für die urbane Wertschöpfung" hingegen zielt eher auf die physische Infrastruktur ab, indem interdisziplinär sog. Open Labs (Fab Labs, die mit Open Source-Werkzeugmaschinen ausgestattet sind) erforscht und das Open Lab Starter Kit (Set aus Open Source-Werkzeugmaschinen, um ein Fab Lab zu betreiben) entwickelt werden.

Nachfolgend werden Struktur und Inhalte des Werks kurz vorgestellt: In **Part I: Frameworks and Theoretical Concepts** wird eine Auswahl theoretischer Konzepte und Frameworks vorgestellt, die der theoretischen und praktischen Herangehensweise an das Fab

City-Konzept zu Grunde liegen. **Part II: Governance, Economics, and Enabling Technologies** handelt von möglichen Governance-Ansätzen, ökonomischen Mechanismen und technologischen Rahmenkonzepten, um eine Fab City aufzubauen, zu gestalten und zu evaluieren. Das Kapitel **Part III: Distributed Innovation, Design, and Product Development** handelt von aktuellen Ansätzen, Chancen und Herausforderungen im Bereich verteilter Ideengenerierung, Produktentstehung, Produktionsplanung sowie Verbreitungsstrategien von Produkten, die in globalen Communities entstanden sind. Neben kollaborativen Formaten und Prozessen wird auch das benötigte technische Ökosystem für die Entwicklung von Open Source Hardware vorgestellt. In **Part IV: Local Production** werden physische Infrastrukturen und lokale Netzwerke für die Produktion im urbanen Raum erkundet. Dabei geht es sowohl um die Produktionstechnologien und -maschinen selbst, deren Bedienbarkeit sowie die Bereitstellung dieser Technologien an öffentlich zugänglichen Orten wie Fab Labs, Open Labs und Microfactories und deren Rolle und Beitrag zur Befähigung von Fab Cities zu lokaler Produktion.

### 1.3.1 Part I: Frameworks and Theoretical Concepts

*Diez et al.* (vgl. Kap. 2) stellen fest, dass für die Umsetzung des Fab City-Konzepts eine multiskalare Herangehensweise erforderlich ist. Sie präsentieren das ganzheitliche Fab City Full Stack-Framework, das sowohl für die Forschung als auch für die Anwendung als Ansatz zur Operationalisierung des Übergangs zu lokal produktiven und global vernetzten Städten und Regionen dienen kann.

*Buxbaum-Conradi* (vgl. Kap. 3) leitet aus der Stadtanthropologie und städtischen Transformationsforschung einen integrativen theoretischen Rahmen für das Fab City-Konzept her, wonach eine Fab City als alternatives Modell zur städtischen Funktionsweise verstanden werden kann. Nach diesem Modell kann eine Stadt oder urbane Region als kosmo-lokaler Raum für Produktions- und Konsumptionsprozesse aufgefasst werden und muss entsprechend neu organisiert werden.

*Krenz et al.* (vgl. Kap. 4) führen uns vor Augen, dass es eines ganzheitlichen Verständnisses von lokaler Produktion bedarf, um dessen Potenziale voll zu entfalten. Sie leiten entsprechende Handlungsfelder ab und beschreiben Schlüsselfaktoren, die sich aus den drei Säulen der Nachhaltigkeit ergeben.

### 1.3.2 Part II: Governance, Economics, and Enabling Technologies

*Roio et al.* (vgl. Kap. 5) erörtern, warum bestehende ökonomische Konzepte und Marktmechanismen den Anforderungen einer global vernetzten und verteilten Entwicklung von (Open Source) Software und Hardware nicht gerecht werden. Sie schlagen ein alternatives Modell (Creative Flows) vor, das insbesondere in der Ideenfindungs- und Entwicklungsphase von Open Source-Projekten Anreize für Kollaboration schaffen soll.

*Wildhack et al.* (vgl. Kap. 6) verstehen den Wandel hin zu einer Fab City als Transformationsprozess, der durch den Ansatz der Transition Governance besser verstanden und unterstützt werden kann. Am Beispiel Hamburgs erläutern sie das Transition Management-Modell und wie es zielgerichtet eingesetzt werden kann.

*Pawlowski* (vgl. Kap. 7) stellt das Konzept der Decentralized Autonomous Organization (DAO) als alternatives und dezentrales Governance-Modell vor und prüft, inwiefern es für die Operationalisierung einer Fab City genutzt werden kann.

*Roio et al.* (vgl. Kap. 8) stellen eine neuartige Digital Product Passport (DPP)-Technologie vor, die besonders für die Anwendung im Kontext global und kollaborativ entwickelter Open Source Hardware geeignet ist. Sie ist zugleich im Einklang mit den Anforderungen der Europäischen Kommission und nutzt modernste kryptografische Mechanismen für eine sichere Übertragung zwischen unterschiedlichen Kontexten.

*Boeing* (vgl. Kap. 9) stellt ein Open Source-Toolkit zur Messung des Status der Kreislaufwirtschaft einer Fab City, den sog. Fab City Index, vor. Er wird mit öffentlich zugänglichen statistischen Daten gebildet und soll in verschiedenen Branchen und Industrien lokale Bedarfe mit lokalen Produktionskapazitäten ins Verhältnis zu setzen.

*Beldiman et al.* (vgl. Kap. 10) untersuchen die Rolle des Geistigen Eigentums in einer Fab City. Sie überprüfen bestehende Open Source-Lizenzen auf ihre Anwendbarkeit im Kontext eines kollaborativen offenen Wertschöpfungssystems wie einer Fab City. Die Juristen kommen zu dem Ergebnis, dass einerseits bestehende OS-Lizenzmodelle nicht ausreichend sind, um einen rechtssicheren Rahmen für Entwickler und Produzenten zu schaffen und andererseits auch bestehende Instrument des Geistigen Eigentumsrechts den Anforderungen eines globalen Netzwerks nicht gerecht werden.

*Haller et al.* (vgl. Kap. 11) analysieren die potenziellen rechtlichen Risiken bzw. für Entwickler und Maker in Bezug auf die Haftung für Personen- oder Sachschäden durch den Aufbau und die Nutzung von Open Source Hardware. Sie kommen zu dem Ergebnis, dass das bestehende Haftungsrecht im Falle einer verteilten Wertschöpfung durch Laien durchaus an seine Grenzen stößt und folglich eine weitere Auseinandersetzung mit diesem Phänomen in der Rechtsforschung erfolgen sollte.

### 1.3.3 Part III: Distributed Innovation, Design, and Product Development

*Schnier et al.* (vgl. Kap. 12) ergründen die Relevanz altruistischer Motive von Teilnehmenden an Citizen Innovation-Formten am Beispiel eines Ideenwettbewerbs in Bezug auf die Qualität von Beiträgen. Sie finden heraus, dass die Einreichungen von kollaborativ eingestellte Personen eine höhere Qualität aufweisen und plädieren daher dafür, kollaborative Elemente bei der Durchführung eines solchen Formats einzusetzen, sodass eben jene Menschen für eine Teilnahme gewonnen werden können.

*Klein et al.* (vgl. Kap. 13) beschreiben ein Anreizsystem für die Verbreitung von Produkten, die in einem Fab Lab durch sog. User Innovators entstehen. Zugleich werden

Adoptionsbarrieren für die Nutzung von Fab Lab-Produkten auf Seiten der Konsumenten erarbeitet und wie diese adressiert werden können.

*Mariscal-Melgar et al.* (vgl. Kap. 14) analysieren das Software-Ökosystem, das für die Entwicklung von Open Source Hardware notwendig ist und die Rolle von freier Software hierin. Sie kommen zu dem Ergebnis, dass noch keine vollständige OS-Toolchain existiert, diese jedoch dringend erforderlich sei, um die Verbreitung von Open Source Hardware weiter zu fördern.

*Kühr et al.* (vgl. Kap. 15) argumentieren, das neue Designansätze erforderlich sind, um den Anforderungen einer zirkulären und verteilten Wertschöpfung in Fab Cities gerecht zu werden. Sie stellen fünf kokreativ entstandene Gestaltungsprinzipien vor, die eine wirksame Umsetzung des Fab City-Konzepts ermöglichen können.

*Saubke et al.* (vgl. Kap. 16) adressieren die Herausforderungen an die Produktionsplanung von Unternehmen bei einer verteilten Produktentwicklung und einer verteilten Produktion. Sie leiten Handlungsfelder ab, die bei der Gestaltung eines offenen und verteilten Produktionssystems berücksichtigt werden sollten.

### 1.3.4 Part IV: Local Production

*Hofer et al.* (vgl. Kap. 17) untersuchen die Rollen und Funktionen von Makerspaces bei der Entwicklung und Verbreitung von Open Source Hardware. Sie finden, dass ein Makerspace als zentrale Infrastruktur, Intermediär und Beratungsstelle eine entscheidende Position bei der Verbreitung offener Technologien und lokaler Produktion einnehmen kann.

*Lange et al.* (vgl. Kap. 18) beschäftigt sich mit Aspekten der Benutzerfreundlichkeit von Open Source-Werkzeugmaschinen, die in Fab Labs und Open Labs zum Einsatz kommen. Einfach und sicher zu bedienende Maschinen, die auch von technischen Laien genutzt werden können, sind ein wichtiger Aspekt bei der Verbreitung dieser Produktionstechnologien. Zugleich ist die Umsetzung dieser Anforderungen nicht trivial. Er werden Schlüsselfaktoren vorgestellt, die bei der Entwicklung der Maschinen berücksichtigt werden sollten.

*Omer et al.* (vgl. Kap. 19) stellt das Open Lab Starter Kit als wichtigen Baustein für die weltweite Verbreitung von Technologie in und durch Fab Labs vor. Es umfasst ein Set aus acht kostengünstigen Maschinen unterschiedlicher Produktionstechnologien, die für den Betrieb eines Fab Labs notwendig sind. Die Werkzeugmaschinen sind als Open Source Hardware dokumentiert und lizensiert sowie als sog. *appropriate technology* robust und offen gestaltet, wodurch eine maximale weltweite Verbreitung ermöglicht werden kann.

*Langhammer et al.* (vgl. Kap. 20) beschreiben konzeptartig, wie eine zirkuläre und offene Produktionsweise mittels sog. Microfactories in urbanen Räumen gestärkt werden kann. Microfactories bauen auf dem Fab Lab-Gedanken auf mit dem Ziel einer professionellen und dennoch offenen, dezentralen und flexiblen Fertigungsumgebung, in der Manufacturing-as-a-Service für professionelle Akteure angeboten werden kann.

*Markert et al.* (vgl. Kap. 21) analysieren, wie lokale Produktion in Form von Netzwerken von Kleinst- sowie kleinen und mittleren Unternehmen ausgestaltet werden könnte.

Sie beleuchten Chancen und Herausforderungen an die Produktionsplanung und stellen heraus, dass dieser Netzwerkkonstellation durch die Anwendung von Industrie 4.0-Prinzipien eine wichtige Rolle auf dem Weg zu einer Kreislaufwirtschaft zugeschrieben werden kann.

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# Teil I

# Frameworks and Theoretical Concepts

# 2 The Fab City Full Stack

## A Multiscalar Framework for an Orchestrated Collaboration Within Distributed Networks of Production

Tomas Diez Ladera, Vasilis Niaros and Carolina Ferro

## 2.1 Introduction

The Fab City Full Stack is a comprehensive framework that aims to transform cities into self-sufficient and locally productive ecosystems (Diez, 2012). It is based on the 'Products In Trash Out' (PITO) to 'Data In Data Out' (DIDO) concept, which envisions a world where any object or tool can be designed, produced, and recycled within in a city, while its digital information can be shared globally and adapted in any local context (Diez, 2016). The Fab City Full Stack (Fig. 2.1) builds upon this vision by providing a roadmap for cities to achieve this level of self-sufficiency and resilience through a combination of digital and physical infrastructure, community empowerment, and local production of things, food, and energy (Guallart, 2014).

The Fab City concept was first introduced at the FAB7 Fab Lab Conference in Lima and later consolidated in the Fab City Whitepaper, which outlined the principles and goals of the movement (Diez, 2016). These principles include the decentralization of production, open and collaborative innovation, and the use of digital fabrication technologies to enable local production. The Fab City Full Stack provides a concrete set of tools and strategies for cities to implement these principles in a systematic and scalable way.

The core of the Fab City Full Stack is self-sufficiency and circularity, so it seeks to reduce the reliance of cities on external resources and minimize waste and pollution. This is achieved through digital technologies such as 3D printing, CNC machines, and robotics, combined with new material supply chains, as well as physical infrastructure such as

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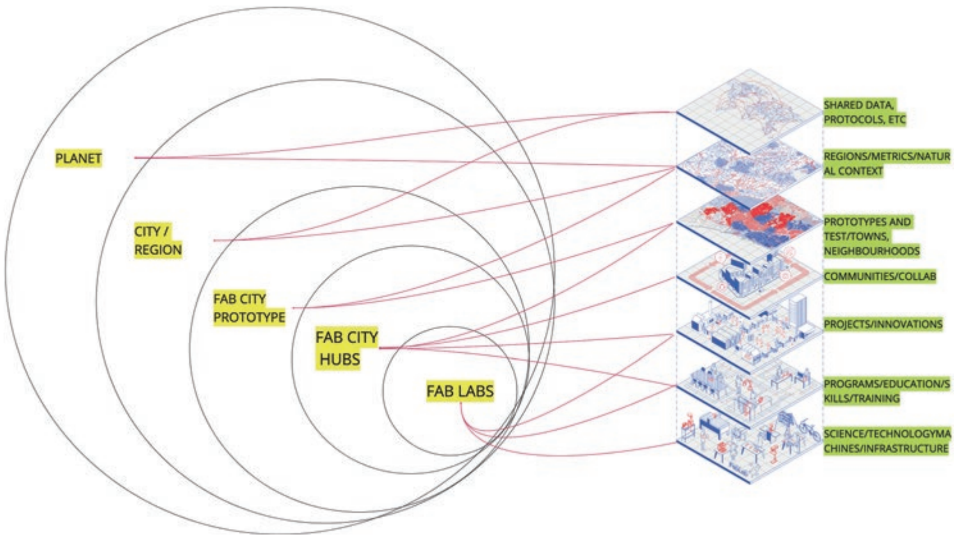


**Fig. 2.1** The Fab City Full Stack in relation to the FCGI action spheres

urban agriculture, renewable energy, and waste management systems. Thus, it introduces a new infrastructure to keep atoms circulating locally, while bits of information circulate globally.

The Fab City Full Stack also emphasizes the importance of community empowerment and local participation, recognizing that the movement's success depends on the active engagement and collaboration of citizens, makers, and entrepreneurs. The *Fab City Manifesto* outlines the key values and principles that underpin this collaborative approach, including transparency, openness, and inclusivity (Fab City Global Initiative, 2018).

In this chapter, we will explore the key components of the Fab City Full Stack and examine the potential benefits and challenges of implementing this framework in cities worldwide. We will draw on examples from existing Fab City initiatives and highlight the role of digital technologies in enabling local production and global exchange of knowledge. Ultimately, we will argue that the Fab City Full Stack serves as an operational tool to build a promising vision for the future of cities, one that prioritizes local resilience, environmental sustainability, and community empowerment.

## 2.2 Theoretical and Practical Roots of the Full Stack

The Full Stack approach has been inspired by theoretical models and practical experiences alike. On the theoretical side, it draws from several disciplines and concepts, such as systems thinking, complexity theory, and the "powers of ten" concept. These theories provide a framework for understanding the complexity and interconnections of different systems, and for considering multiple scales when designing interventions in the Fab City Global

Initiative context. On the practical side, the Full Stack approach has been inspired by a number of real-world initiatives and projects, such as the Fab Lab network, which provides access to digital fabrication technologies and supports local manufacturing (Gershenfeld et al., 2017). The evolution of programs, such as the Fab Academy, allowing innovations to be spurred by student's creativity, and the implementation of Fab Labs in several countries in the world, have informed the development of the Full Stack framework. It recognizes the need to articulate the efforts of distributed networks (Armstrong and Diez, 2021) to increase impact and accelerate the transition towards a new productive model in cities and regions.

On the theoretical side, the "powers of ten" concept (Eames and Eames, 1977), popularized by the eponymous Eames film, emphasizes the importance of considering multiple scales for the analyses and designs of systems. This concept has been integrated into the Full Stack approach, emphasizing a multiscalar approach to designing solutions for complex problems. In addition, the concept of "pace layering" is a framework that recognizes that a system's different components change at different rates and have different life spans. The framework was first introduced by Stewart Brand (1999) and has since been applied in various fields, including architecture, urban planning, and software design. In the context of the Fab City Global Initiative and the Full Stack framework, the concept of pace layering is essential because it recognizes that systems are made up of multiple layers which operate at different speeds and have different degrees of resilience. The Full Stack approach emphasizes the importance of designing solutions that address complex problems at multiple scales, and pace layering provides a framework for doing so. For example, the pace layering framework might be used to design a local manufacturing network that uses digital fabrication technologies. The physical infrastructure layer might be designed to last for several decades, while the software and data layers might be updated more frequently to keep pace with changing technologies and needs. The governance and cultural layers might evolve more slowly but are no less important for the project's long-term sustainability and success.

Moreover, "leverage points" are key aspects of a system in which small changes can have a large impact on the sustainability and resilience of said system. Donella Meadows (2008) first introduced this concept in her book *Thinking in Systems: A Primer*. Leverage points can be identified in various aspects of a system, where a small change can significantly impact the sustainability and resilience of that system. For instance, in the design of a transportation network, a leverage point might be identified in the choice of vehicle fuel, where a shift to electric or hybrid vehicles can lead to a significant reduction in greenhouse gas emissions. By making this change and promoting the use of these vehicles, designers can create a more sustainable and resilient transportation system. Another example can be in the design of a local manufacturing network that utilizes biomaterials, where a leverage point might be identified in the choice of materials used. By selecting and promoting the use of sustainable biomaterials, designers can significantly reduce the network's environmental impact, such as reducing the use of non-renewable resources. In the context of a city that utilizes blockchain applications, leverage points might be identified in areas such as energy use and supply chain transparency. For instance, it might be identified in the use of renewable energy to power blockchain applications, where a small change in energy source can lead to a significant reduction in carbon emissions. Additionally, the use of blockchain technology can provide greater transparency in supply chains, improving the city's overall sustainability and resilience.

Finally, "bioregionalism" is a way of understanding and organizing human societies around the natural systems and ecosystems in which they exist (Van Newkirk, 1975). Bioregionalism emphasizes the importance of localism, sustainability, and community-building, with a focus on developing self-sufficient and resilient communities integrated into their natural environment. In the context of the Full Stack's holistic and ecosystemic approach to building sustainable and resilient cities, the concept of bioregionalism is an important tool for designing solutions deeply integrated with the natural environment and the inhabiting communities. By understanding and working within a particular region's natural systems and ecosystems, designers and planners can create more effective and sustainable solutions in the long run (Wahl, 2020). For example, a bioregional approach to urban agriculture might involve using locally adapted crops and agroforestry systems that are suited to the local climate and soil conditions. This approach would prioritize the use of locally available resources, reducing the need for external inputs and transportation. Additionally, a bioregional approach might involve creating community-supported agriculture programs that connect local farmers with consumers, promoting social and economic resilience.

By drawing on theoretical and practical inspiration, the Fab City Full Stack approach can combine a deep understanding of the underlying principles and concepts with a practical focus on creating effective and sustainable solutions in the real world. This combination of theory and practice makes the Full Stack approach such a potentially powerful tool for addressing complex problems and designing solutions with a positive impact on the people and the planet, and to articulate and coordinate efforts with the Fab City Network members.

## 2.3 The Fab City Full Stack

The Fab City Full Stack is a multiscalar framework for distributed production strategies in cities and regions (Diez et al., 2022). It is needed to articulate an ambitious project such as the Fab City Global Initiative, which aims to transform cities to self-sufficiency regarding the production of their own goods by 2054. The Full Stack's seven layers (Fig. 2.2) provide a structured pathway for communities and (policy)makers to create local networks and initiatives grounded in shared values, principles, and goals. It helps cities and regions to take a holistic approach to sustainable development, and to work towards a circular economy by promoting distributed production and consumption. Lastly, the Full Stack can be adapted and customized to the needs of specific cities and regions.

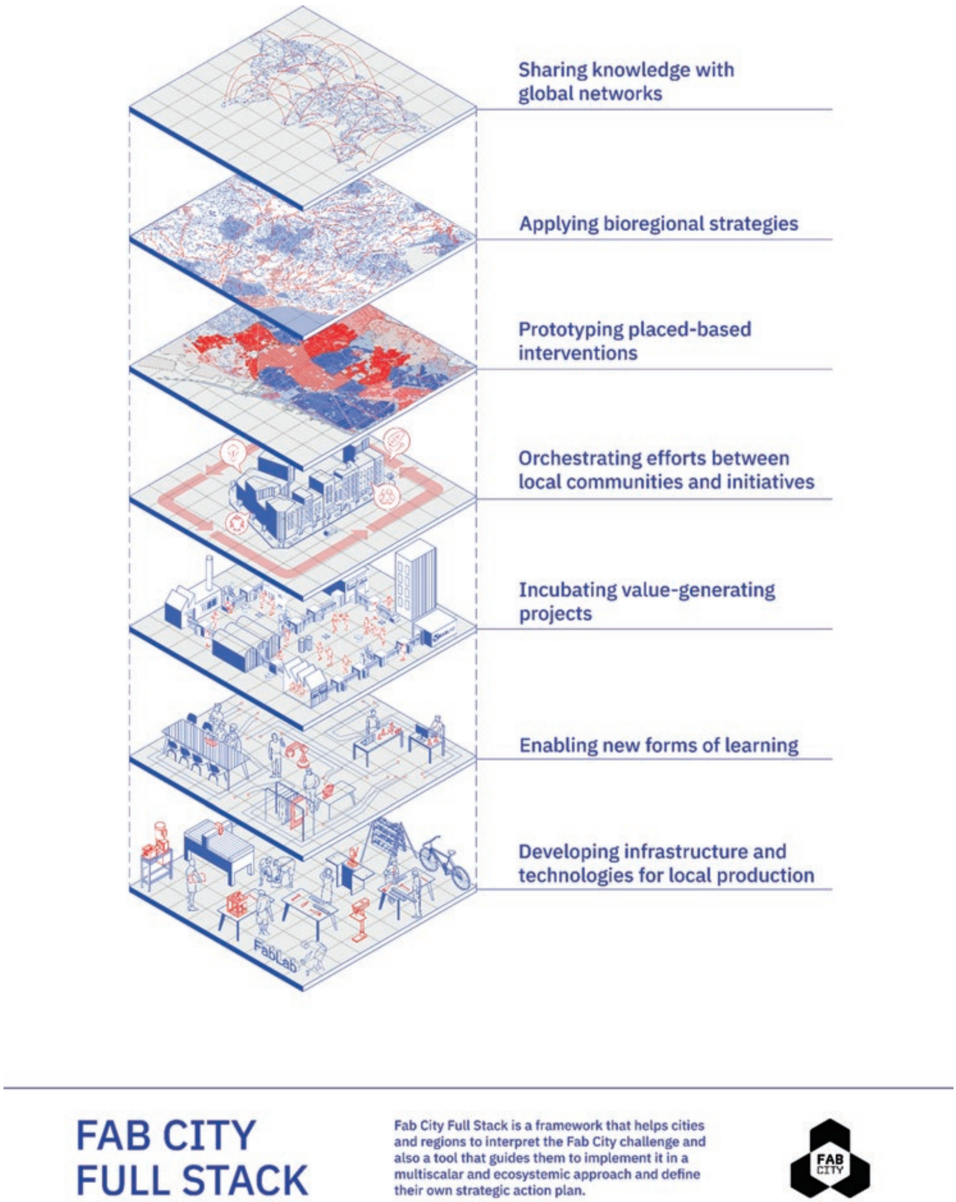


**Fig. 2.2** The seven layers of the Fab City Full Stack

The Fab City Full Stack's seven layers provide a comprehensive approach to transitioning towards a new productive model that fosters sustainability, innovation, and social inclusion. These layers range from the necessary infrastructure and technologies for local production to sharing knowledge between local and global networks. The seven layers are:

**Layer 1: Developing Infrastructure and Technologies for Local Production** The first layer encompasses the essential local innovation spaces such as Fab Labs, makerspaces, hackerspaces, creative hubs, as well as industrial-level infrastructure in cities and bioregions. It is crucial in supporting the transition towards a new productive model in which atoms stay local and bits travel globally. The layer's primary objective is the application of scientific knowledge to sustain, regenerate, and nurture life in Fab Cities. The Center for Bits and Atoms (CBA) at MIT and the global Fab Lab Network has been fundamental in designing future machines, exploring alternative materials, and fabrication processes, paving the way for the new industrial paradigm the Fab City Global Initiative is aiming to build, grounded in science and technology to develop a new production infrastructure and material ecology aligned with life-supporting systems at the planetary scale. Furthermore, this layer aims to build a sense of shared ownership around community production spaces, promoting values such as openness, inclusivity, and sharing, beyond the machines and materials.

**Layer 2: Enabling New Forms of Learning** The second layer involves the enabling of new forms of learning that support the development of skills and knowledge needed to implement a new production paradigm in society, economy, and culture. As the Center for Bits and Atoms democratizes their work through situated labs and open knowledge, it facilitates the development of such skills and knowledge. The Fab Lab Network is leading new approaches to education through the development of a distributed model of learning programs contextualized locally and articulated globally, which can be seen in initiatives such as the Academy of Almost Anything and other emergent educational programs such as the Master in Design for Distributed Innovation. By incorporating digital fabrication tools, principles, machines, and processes into formal education and emerging new programs, these new forms of learning can help develop creative and critical skills at all levels.

**Layer 3: Incubating Value-Generating Projects** This layer enables the development of hands-on projects that have economic, scientific, and social impact at the local scale. Fab Lab skills are utilized to transform designs from distributed networks into innovative projects through prototyping and experimentation. Layer 3 focuses on nurturing social and entrepreneurial projects that strengthen the principles of the Fab City Global Initiative and transform the existing productive paradigm at multiple scales. Additionally, frameworks, methods, and business models are developed to support the utilization and development of these innovation projects.

**Layer 4: Orchestrating Efforts Between Local Communities and Initiatives** The fourth layer emphasizes the importance of community engagement for Fab Labs, makerspaces, and hackerspaces. It acknowledges the need to establish new local networks based on shared Fab City values and goals. This layer aims to bring together existing local efforts and incentivize an active participation of the community in innovation projects with local impact. To achieve this, Fab City Hubs serve as physical interfaces to connect various actors such as neighbors, citizens, makers, organizations, businesses, and public entities. These hubs encourage collaboration and facilitate the exchange of skills and knowledge among local communities in a given territory, thereby expanding the role and reach of Fab Labs and makerspaces.

**Layer 5: Prototyping Place-Based Interventions** Creating prototypes of the Fab City model is crucial to the alignment of projects developed in Fab Labs and Fab City Hubs with their local ecosystems. The fifth layer comes into play here, focusing on prototyping place-based interventions (SPACE10 & FranklinTill Studio, 2017). These prototypes are developed at various scales, from neighborhoods to entire cities, aiming to create local strategies and governance models that can influence policymaking and establish a favorable legal framework for implementing Fab City projects. By establishing experimentation playgrounds for innovative business opportunities, citizens can test and iterate ideas that support the development of a circular economy. The ultimate aim is to establish the necessary urban frameworks and lighthouses that guide policymakers to scale the results to metropolitan and bioregional levels.

**Layer 6: Applying Bioregional Strategies** The physical location of labs, hubs, and projects influences their work and has an impact on multiple scales, including the city or region they are situated in. A bioregional approach to the transition to a new productive model can foster a better relationship between humans and other species. Bioregions are defined by each territory's cultural relationships and natural systems, allowing us to operate on a territorial scale large enough to understand cities beyond their artificial, physical, or political limits. Bioregions operate within a global logic and are influenced by changes in climate and interdependence of natural systems. It is impossible to neglect this relationship between the biological and synthetic within the same spatial and cultural dimensions that compose them. Therefore, any intervention in cities or regions must recognize this multi-species approach.

**Layer 7: Sharing Knowledge with Global Networks** In the context of the Fab City Full Stack, the process of knowledge exchange and sharing is crucial to the initiative's overall success. This is because it enables the transition from a traditional model of production known as PITO (Product In, Trash Out) to a potentially more sustainable model known as DIDO (Data In, Data Out). DIDO centers around the idea of local production and consumption, where cities are able to produce most of what they consume within their own borders and minimize waste by reusing and recycling resources. This needs knowledge exchange and collaboration across local and global networks to support the development and implementation of new technologies, processes, and business models. This knowledge exchange occurs in various local contexts, such as Fab Labs, hubs, neighborhoods, and bioregions, where individuals and groups collaborate to share information and co-create innovative solutions tailored to local needs and contexts.

In addition to enabling knowledge exchange, it is also important to develop metrics to measure progress towards the goal of producing (almost) everything locally by 2054. These metrics can help track the impact of various interventions and initiatives and provide insights into how to improve and scale up successful projects. By measuring progress towards a circular economy and local production, cities and regions can identify areas for improvement and make informed decisions about the allocation of resources to achieve their sustainability goals. Ultimately, the success of the Fab City Full Stack depends on the ability of local and global networks to share knowledge and collaborate towards a common goal, as well as the ability to measure progress towards a sustainable future.

## 2.4 Ways of Using the Fab City Full Stack

The Fab City Full Stack provides a comprehensive framework that can be used to analyze, design, and implement projects within the Fab City philosophy. By breaking down the complex web of interrelated factors that contribute to the development of distributed production strategies, the Full Stack allows for a more focused and efficient approach to addressing the challenges faced by cities and regions around the world. The Full Stack is also a tool for empowering local communities to connect, learn, collaborate, and innovate, while at the same time keeping them connected to a global community that shares the same vision for a more sustainable and equitable future.

**As an Analysis Tool** The Fab City Full Stack can be used to analyze a context before designing and implementing a project. The analysis starts by understanding the local context and identifying the needs, resources, and actors involved. Then, the project's potential impact on the local community and the environment should be evaluated, considering social, economic, and environmental factors. Finally, a design that responds to the identified needs and takes advantage of available resources can be created, followed by implementation and continuous evaluation to ensure that the project is achieving its intended goals. The Full Stack provides a framework to guide this process, ensuring that projects align with the values and principles of the Fab City philosophy.

**As a Design Tool** The Fab City Full Stack provides a framework for designing projects and interventions that align with the Fab City principles. By utilizing the various layers of the Full Stack, designers and stakeholders can analyze the project's context and identify its key challenges, resources, and opportunities. This understanding can inform the design of appropriate technologies and strategies, as well as identify potential partners and collaborators. By using the Full Stack to design a project, stakeholders can ensure that it aligns with the values of the Fab City philosophy, such as circularity, sustainability, and open access. The Full Stack can also aid in the project's implementation by providing guidance on community engagement, business models, and local governance.

**As an Implementation Tool** The Fab City Full Stack can be used to implement projects by providing a roadmap for translating Fab City principles into action. The Full Stack offers a framework for navigating the complexity of implementing a transition to a sustainable, locally productive city model. It helps to ensure that projects are aligned with the values of the Fab City Global Initiative, including open source, community engagement, and sustainability. The Full Stack can be used to establish local networks, develop skills and knowledge, and create prototypes at different scales. By working through each layer of the Full Stack, projects can be designed and implemented to promote a circular economy and contribute to a regenerative and thriving local and global ecosystem.

## 2.5 Case Studies

To demonstrate the practical application of the Fab City Full Stack framework, we examine three case studies. The first case study focuses on some of the Fab City Network members, and how they have implemented the Full Stack in different ways. The second case study explores the Smart Citizen project and how it aligns with the principles of the Full Stack. Last, the third case study analyzes the Master in Design for Distributed Innovation program offered by Fab City Foundation and IAAC and how it applies the Full Stack principles to education and innovation. Through these case studies, we demonstrate how the Fab City Full Stack framework can be used to design and implement projects that align with the principles of the Fab City Global Initiative, while also addressing the specific challenges and opportunities of each context.

### 2.5.1 Cities as Case Studies

Barcelona is the pioneering city in the Fab City Global Initiative. Back in 2014, Xavier Trias, the then Mayor of the City, launched a global challenge for cities to produce almost everything they consume by 2054. Under the leadership of new Mayor Ada Colau, Barcelona has focused on developing infrastructure and technologies for local production in collaboration with local stakeholders such as Fab Lab Barcelona at IAAC (IAAC, n.d.). The city has established a number of innovation spaces and digital fabrication tools to support the transition towards a new productive model of the city (Barcelona City Council, 2014). Further, the city has been incubating value-generating projects by creating frameworks, methods, and business models that support the development and utilization of such innovation projects through local programs such as the Proactive City (BIT Habitat – Barcelona City Council, n.d.).

Another example of a city is Paris, which has been actively working towards becoming a more sustainable and resilient city by implementing various circular economy strategies, some of which are efforts within the C40 Initiative, the development of the 15-minute city (Allam et al., 2022, 181–183) and by joining the Fab City Network. Paris has a long history of industrialization and urbanization. However, in recent years, the city has been facing challenges related to climate change, such as air pollution and the depletion of natural resources. The city has also been orchestrating efforts between local communities and initiatives by collaborating closely with the Fab City Grand Paris Association, founded by local organizations committed to the Fab City principles. The Association has played an important role in orchestrating efforts between different organizations so far, and in the implementation of Fab City Prototypes in city's neighborhoods (SPACE10 & FranklinTill Studio, 2017). Most recently, the efforts of local Association members have contributed to the development of Fab City Hubs (CENTRINNO EU, 2022), which act as physical interfaces to connect multiple actors like citizens, makers, organizations, businesses, and public entities. Moreover, the city has been prototyping place-based interventions by creating strategies and governance models as well as influencing policymaking for the development of a favorable legal framework for an implementation of Fab City projects.

Inspired by Paris, the Fab City Hamburg Association brings together various stakeholders, including citizens, businesses, and public institutions, to work towards a more sustainable and self-sufficient city model. The Association seeks to promote the principles of the global Fab City movement at the local level, focusing on creating local networks, developing skills and knowledge, and fostering innovation projects that align with the movement's values. The Fab City OS, a digital platform for sharing knowledge, resources, and skills related to sustainable urban development, is one of the projects extremely relevant to layers of the Full Stack (Fab City Hamburg Association, 2022). It offers a range of tools and resources, including an open-source data platform, a skills exchange network, and a marketplace for locally produced goods and services. The Fab City Hamburg Association is also actively involved in the development of open-source technologies that support local production in cities.

These examples show how different cities work on various layers of the Fab City Full Stack. One of the benefits of having a shared framework is for cities to be able to implement some of the existing layers developed by others, in their local context, and contributing back to its development and evolution. However, the main challenge for cities during their implementation of the Fab City Full Stack was the lack of coordination and collaboration between different government agencies and private entities. Some of these cities have been successful in creating a sense of community around innovation spaces with shared values such as openness, inclusivity, and sharing, yet, still, it is an additional challenge to increase the participation of cities and regions from areas outside the European context, one of the main focuses of the Fab City Foundation.

### 2.5.2 Project as a Case Study

The Smart Citizen project is a citizen-led initiative that emerged from the Fab Lab Network and aims to empower citizens to collect, share, and understand data on their environment. The project follows the Fab City principles by re-localizing the production of energy, food, and products, and developing infrastructure to keep atoms moving at the local level and bits travelling globally.

The Smart Citizen project was developed by Fab Lab Barcelona in collaboration with other organizations (Fab Lab Barcelona – IAAC, 2012). It was created with the goal of providing citizens with a tool to measure and understand the environmental conditions in their neighborhoods, aiming to foster a more sustainable and resilient city. The Smart Citizen project consists of a kit that includes sensors and a microcontroller used to measure a variety of environmental conditions, such as temperature, humidity, noise, and air quality. The data collected by the sensors is then shared with the community through a web platform and mobile app, allowing citizens to access and understand the data in real time. The project also includes a learning component, with workshops and tutorials that teach citizens how to assemble and use the kit, as well as how to interpret and make use of the data.

By incubating value-generating projects, the Smart Citizen project creates a community of active citizens who are aware of the environmental conditions in their neighborhood and can take action to improve them. Additionally, the project encourages collaboration and networking between citizens, organizations, and public entities, allowing them to work together to improve their environment. One of the main challenges faced by the Smart Citizen project was the need to ensure the accuracy and reliability of the data collected by the sensors.

### 2.5.3 Educational Program as a Case Study

The Master in Design for Distributed Innovation (MDDI) offered by the Fab City Foundation and the Institute for Advanced Architecture of Catalonia (IAAC) can serve as a case study for the Fab City Full Stack for several reasons. Firstly, the MDDI program focuses on developing the necessary skills and knowledge to contribute to the development of distributed and collaborative production systems, a key aspect of the Fab City Full Stack. The program equips students with skills to design, prototype, and implement products and services that contribute to more sustainable and self-sufficient communities.

Secondly, the MDDI program provides a platform for students to engage with the principles and values of the Fab City Full Stack, such as circular economy, open-source design, and participatory governance. The program encourages students to explore how these principles can be integrated into their design practice, and to develop projects that contribute to creating more equitable cities.

Thirdly, the MDDI program offers a unique opportunity for students to engage with the Fab City Global Initiative, which is at the forefront of the movement towards more sustainable and self-sufficient cities. Students have the opportunity to work on real-world projects aligned with the Fab City Full Stack, and to engage with a global community of practitioners working towards a common goal.

Overall, the MDDI can serve as a case study for the Fab City Full Stack because it embodies the values and principles of the Fab City Global Initiative, and it provides students with a platform to learn the necessary skills and gain knowledge to contribute to the development of more sustainable and self-sufficient cities. The program offers a unique opportunity for students to engage with the Fab City Full Stack and to contribute to the development of innovative solutions with real impact.

## 2.6 Conclusions and Further Research

The Fab City Full Stack is still a conceptual framework that needs to be tested and iterated within the Fab City ecosystem, especially in the network of cities and regions where the Fab City agenda has been adopted. As an analysis tool, it enables stakeholders to understand the local context and evaluate a project's potential impact. As a design tool, it provides a framework for the design of projects and interventions that promote circularity, sustainability, and open access. As an implementation tool, it offers a roadmap for the translation of Fab City principles into action, helping to establish local networks, develop skills and knowledge, and create prototypes at different scales.

The case studies presented in this chapter demonstrate the versatility and effectiveness of the Full Stack in guiding the development of innovative and sustainable projects. The success of the Full Stack depends on strong community engagement, partnerships with local organizations and businesses, and a willingness to experiment and iterate projects and interventions. However, as with any framework, its implementation has its challenges, including the need for more in-depth focus on the social, economic, and political dimensions of the framework, and the development of metrics to measure progress towards self-sufficient and sustainable cities and regions.

Future directions for research on the Fab City Full Stack include further exploration of the framework's usage to analyze complex urban systems, such as the relationship between cities and their surrounding bioregions, and its usage for the creation of more inclusive and equitable urban spaces. There is a need for research on the Full Stack's (potential) integration into existing policy frameworks at the local, national, and international levels, as well as how it can be used to inform and shape future policy decisions in areas such as manufacturing, housing, food, energy, amongst others.

Additionally, research could explore the potential of integrating digital technologies, such as blockchain, into the Fab City Full Stack to enhance collaboration and transparency, and to understand the role of governance and policymaking in supporting the Stack's implementation at the local and global levels.

Future research can focus on evaluating and measuring the impact of Fab City projects and interventions. This includes the development of metrics that capture the social, economic, and environmental impacts of projects, and of tools to assess the effectiveness of the Full Stack as a framework for guiding project development. Fab Cities can use qualitative and quantitative methods to measure their impact and employ a multiscalar approach that considers the impact at the system's different levels, ranging from the local to the global scale. Fab Cities can also leverage the concepts of leverage points and pace layering to identify the most effective interventions for achieving their goals. By tailoring interventions to each layer's specific needs, Fab Cities can have a greater impact on the overall system. For instance, interventions that promote open-source design and collaborative production can target the Full Stack's first layer, which focuses on developing infrastructure and technologies for local production.

Overall, the Fab City Full Stack could potentially be a valuable tool for urban planners, designers, and policymakers to guide the development of more sustainable and regenerative cities and regions.

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# What Kind of City is the Fab City?

3

## Some Theoretical Groundings and Intellectual Predecessors of the *Fab City* Project

Sonja Buxbaum-Conradi

## 3.1 Introduction

> "Cities are, above all, physical spaces which produce surprising things, reacting like a catalyst for the unexpected." (Antoine Picon[1])

Very little attempts have been made so far to theorize the suggestions made by the Fab City project in terms of the kind of urban functioning and trace back its intellectual predecessors and conceptual underpinnings. Exceptions can be mainly found in Rumpala (2018, 2023) as well as Diez (2016, 2021), with the latter being one of the founders of the Global Fab City Initiative. Yet it remains unclear, what kind of city the Fab City actually is and in how far it challenges the meaning of cities in old or new ways.

Looking back in history, all moments of expansion or decay of economic systems – with their inherent function of creating and distributing value in society – are linked to the importance of cities rather than nation states or kingdoms. This does not change in the information age. Cities are the central sites for the generation of value and the material basis of power, cultural production and social selection (Hall, 1998). Living in a networked society, the global processes of urbanisation taking place in the early twenty-first century are marked by a profound spatial transformation as a fundamental dimension of this new social structure. Global processes of urbanisation have established new global networks con-

[1] VINCI Group (2018).

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M. Moritz et al. (Hrsg.), *Global collaboration, local production*, SDG – Forschung, Konzepte, Lösungsansätze zur Nachhaltigkeit,
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necting metropolitan areas and their radius of influence (Castells, 2010a). This interconnectedness becomes particularly visible in the economic system and its dependency on global production networks as part of the globalisation, diversification and specialization of value chains that are spread across the planet. The development has fostered global integration, but at the same time established strong interdependencies and unequal developmental outcomes with massive ecological consequences that become particularly visible in the realm of cities.

Until now, cities relied predominantly on linear production models based on massive energy consumption and lacking waste recovery. Since urbanization is growing rapidly assuming that 68% of the world's population will live in cities by 2050 (UN Development Report on World Urbanization, 2018) policy makers and city dwellers, are seeking for strategies that enable circularity of material flows and a stronger overall resilience and self-reliance of cities when it comes to productive models and related consumption patterns.

This is where the **Fab City project** enters the debate. It can be best described as a collective experiment seeking solutions to the above outlined challenges articulated by a globally connected urban social movement of designers, academics, engineers, architects and makers that have evolved from the Fab Lab Movement initiated by MIT roughly 20 years ago. The Fab City project reminds us that cities are not only major spaces for economic activity (i.e., production) but also central places of collective or shared consumption. This addresses recent criticism in terms of which economy and urban analysis have historically established a disjunction between production and consumption. What tends to distinguish the strategies carried out with the Fab City project from other currently dominating strategies for urban transformation can be summarized in four aspects that are recaptured and rearranged: the organization of flows, the availability of resources and technological capacities for urban functioning in the urban fabric, the involvement of citizens in productive activities and the type of productive system that is suggested by the project's proponents (i.e., relocalized, distributed, self-sufficient) (Rumpala, 2018).

However, the so-called *Fabrication City* thus far belongs partly to the imagination (or rather the imagination of stakeholders that are carrying it forward). It appears as a set of images and practices associated with the possibility for cities to become self-sufficient, reaching a new balance between environment and economic development, between quality of life and efficient use of resources through the access to and widespread use of information, communication and digital fabrication technologies.

So, the question at hand is: what kind of city is the Fab City? What kind of space- and place-based images are defining and what kind of model for urban functioning is suggested? The aim of this contribution is to ground the ideology behind the Fab City project in prior theoretical work and related imaginations of cities in the field of urban anthropology and urban transformation. This is necessary to provide a more consistent and scientifically profound integrative framework to which future research from different disciplines can relate serving as a common ground of what can be understood as a *Fab City*. Based on document analysis of material provided by the project and the author's experiences resulting from the engagement with the Fab City community throughout two publicly funded research and development projects, the rationale behind it is reconstructed and discussed.

The first part of the chapter gives a brief introduction and overview on how cities have been conceptualized and theorized (i.e., imagined) in prior work in the field of urban studies. It is argued throughout this section that a lot of the intellectual predecessors and ideas that the Fab City Vision is based on relate to the social theorist Manuel Castells' work. What makes this particularly valuable is that he has linked observations of social movements and community-based approaches to urban transformation to the role that information and communication technologies play in creating a new industrial space that is able to link multiple scales. The second part of the chapter specifically analyzes the core principles of the Fab City approach and its conceptual underpinnings in the work of Castells (and related findings) and identifies those aspects that are not yet considered (or at least not considered together) in prior theoretical conceptualizations. The final section integrates the findings from the analysis into a coherent picture and concludes with an outlook for future research especially in the field of social science.

## 3.2 Central Imaginations of Cities and Urban Transformation in the Post-Modern Age

"Theorizing the city is a necessary part of understanding the changing post-industrial, advanced capitalist, postmodern moment which we live in." (Low, 1996, p. 387) – There exists a broad range of ideas, concepts and frameworks used to analyze, write and communicate about an often elusive and discursively complex subject.

The first question that arises here is the question of how cities have been imagined and conceptualized in terms of **urban functioning**. What are essential urban functions and how can cities be described and analyzed? Urban analysis usually links perspectives from various fields such as architecture, geography, urban planning, sociology, economics and history. Different approaches in different disciplines take different access points to the analysis of cities from the social organization of space to the organization of flows, the meanings of knowledge, group and power as well as the intricacies of commodity, exchange and political economy (Low, 1996). The **value of an anthropological perspective** here is to frame a common imagination of cities and urban functioning that helps to link experiences to structure (i.e., abstract models) (Low, 1996, p. 384). This is also necessary to maintain a critical relationship with normative proposals and to consider collective dynamics. Those can be reconstructed by studying the discourses produced and the practical extensions given to them by the actors concerned (Rumpala, 2018).

To begin with, one important distinction in the conceptualization of cities is the difference between space and place. In geography as well as anthropology, space and place are different yet related concepts. "Space" refers to a dimension in which matter is located, an objective three-dimensional extension of reality (Low, 2017). It can be, to some degree, displayed mathematically (e.g., coordinate systems, size). Contrary, “place” is what gives a space meaning. It is linked to human experiences and the culturally ascribed meaning given to a space. “It is the ‘vibe’ that you get from a certain space, and it exists for a reason.” (Fink, 2019) That reason is to create common identity and cultural meaning, to create a sense of belonging. Neither space nor place is static. Space moves in time and the meaning of places is subject to change. Different communities can ascribe different meanings to the same space. Although place-based struggles and conflict lines might be the same throughout younger history, the common conceptualization of space and the distinction between place and space as well as the matter that traditionally constitutes cities has been challenged with the further elaboration and diffusion of digital technologies (Picon, 2018, p. 272).

It was especially the work of Manuell Castells on the *Informational City* and the *Networked Society* that has promoted the conceptualization of the urban space as a network (e.g., the networked metropolis) providing the infrastructure for what he has termed the “space of flows” (Castells, 1991a). More than three decades ago, Castells wrote: “We are moving from a materially-constructed, historical space to a technologically deconstructed space based upon the ability to constantly reprogram according to the interests of the different interactive elements in the process of flows” (Castells, 1991a, p. 14). In 1996, the architect and urban designer William J. Mitchell predicted in his famous book *City of Bits: Space, Place and the Infobahn* that the diffusion of digital technology would ultimately lead to a decrease of physical circulation (i.e., circulation of material flows) in cities (Mitchell, 1996). Apparently, he has been proven wrong, at least until now. The imagination of the city and its economic system as a space of (informational) flows is certainly a manifestation of the *zeitgeist* in the early 1990s being associated with the emergence of the “New Digital Economy” and the “relational turn” of conceptualizations of space in geography and cultural sciences (Boggs & Rantisi, 2003). It had a profound impact on many contemporary images of futuristic cities.

In this very prominent imagination, the city is conceptually more or less detached from its actual natural environment. The focus is on the technical space (in terms of urban functioning) rather than the city as a place linked to human experiences and interaction with their (natural) environment. Material and informational exchanges (i.e., flows) resulting from human production and consumption activities are rarely considered in an integrative manner. The city is viewed through the prism of machine metaphors inspired by neo-cybernetic imaginations of idealized spaces of flows that can be designed or “reprogramed according to the interests of the different interactive elements in the process of flows” (Castells, 1991a, p. 14). This image is still fundamental to more recent advances in conceptualizing what is termed a smart or algorithmic city understood as a network of algorithmically mediated social relations.

The initial conceptualizations and powerful metaphors developed throughout and after the 1980s seem to be coming up against their limits due to the increasing impact of environmental constraints and a growing criticism on the logics of cognitive capitalism and the global distribution systems that it has created (Picon, 2018). It is still unknown though how humans and non-humans (i.e., machines, computing devices, digital infrastructures, ecological systems) can be linked within a city that might become ‘smart’ in a much more literal sense than is often imagined today (Picon, 2015).

It is one thing to imagine urban functioning and the city as an abstract space of flows. The consequence of such a perspective is that it has very little in common with how people are actually experiencing spatial practices and the city in their daily lives, how they make use of and create flows and how they engage in economic activity and consume resources (Low, 2017). Consequently, the subsequent question here is how to imagine the **city as a place**, how do people ascribe meaning to it and how is this meaning changing? How can we imagine the city as something other than a neo-cybernetic machine that organizes flows according to the logics of capital growth models?

When it comes to strategies of urban transformation and **the analysis of urban social movements,** the focus of researchers is, indeed, rather on the city as a place than the city as a space. In this regard, once again, Manuel Castells has provided valuable insights and his definition of urban social movements might be more topical than ever in combining struggles over collective consumption with those for community culture and self-determination (Miller, 2006; Mayer, 2006). According to his famous writings in the *The City and the Grassroots* that synthesized a decade of his (ethnographic) field work and a broad spectrum of cross-national texts on urban mobilizations, he came to the conclusion that, while being unable to transform society, urban-oriented mobilizations do transform urban meanings through undermining societal hierarchies that usually structure urban life. Instead, they create “a city organized on the basis of use values, autonomous local cultures and decentralized participatory democracy” (Castells, 1983, pp. 319–320).

Of course, urban movements have transformed their goals, strategies and organizational structure since the 1960s and 1970s (the time of his fieldwork). Meanwhile, urban elites and policy makers have identified and integrated the activation potential of local civil society groups (Mayer, 2006). Integrative programs nowadays directly involve social movement organizations as stakeholders in public-private-partnership constellations, and urban planners (at least in the EU and the US) are increasingly employing participatory models. In doing so, they are able to make use of the “territorial identity” and the “capacity-building” competence of local movement groups, even if they follow and implement their own visions of sustainable neighborhoods and social economy. However, as also concluded by Castells (2010b) in *The Rise of the Network Society*, in today’s globalized ‘space of flows’ places no longer serve as the ultimate basis for social power, thus, local movements can be easily outmanoeuvred by larger developmental forces. Local movements can connect each other into global networks Consequently, one question remains: how do specific incidences, forms, relations, and effects of these cosmo-local mobilizations challenge the meaning of cities in old or new ways (Mayer, 2006, p. 205)?

So, in order to promote the transformation of meaning of the city, place-based actors have been increasingly integrated in **strategies of urban transformation** to make use of their territorial identity- and capacity-building competence. Currently, there are three dominating strategies for urban transformation: circular, smart, and resilient cities. Faced with multiple challenges, cities have been promoted to take advantage of the latest technological advances in information and communication technologies, to become what is imaged as being "smart". Since the mid-2000s, the still rising issue of "smart cities" has allowed communities of actors from various backgrounds (municipalities, private sector service providers, experts, engineers) to reintegrate urban infrastructure and governance into an optimized and highly technicalized management of flows. Nowadays, the three concepts have evolved into a rather multi-objective and participatory strategy that aims at tackling environmental deterioration and other external shocks while trying to foster sustainability through circular approaches (Ascione et al., 2021), inclusion and building social capital (Bibri & Krogstie, 2017; Cañavera-Herrera et al., 2022).

After this brief introduction into some major fundaments of theorizing the city in the post-modern age and summarizing recent strategies for urban transformation, the questions are now: what is behind the Fab City project? How does it relate to existing theoretic explanations? What kind of model for urban functioning does it suggest? And on what type of space- and place-based images does it rely?

## 3.3 What Is Behind Fab Cities?

Proponents of the Fab City approach aim to radically transform how cities meet their needs and produce necessities themselves (Diez, 2021). According to them, Fab Cities bear the potential to support "the development of localized circular economies that can transform the waste system and waste paradigm" (Ramos et al., 2021, p. 15). This is estimated to support "cities and regions in becoming auto-productive, to form complex cosmo-local value chains for greater resilience' and keep 'production within planetary boundaries' (Ramos et al., 2021, pp. 15–16).

The idea of a Fab City is said to have originated around 2010/2011 and has been further institutionalized as a concrete strategy for urban transformation in 2014 during FAB10, the 10th global annual reunion of the Fab Labs network issued by IAAC, MIT's Centre for Bits and Atoms, the Fab Foundation and the Barcelona City Council around prominent protagonists of urban planning, architecture and urban transformation such as Vincente Guallart and Antoni Vives (Rumpala, 2018). Given its origins in the field of engineering (and urban planning), it is marked by a strong techno-optimism, while it follows, at the same time, a community- and human-centered approach. During the last eight years it evolved into a global association that has gathered 44 cities and regions as well as the first so-called Fab Nation (i.e., Bhutan) under the common vision of becoming 'auto-productive' by 2054. It is pushed forward through local communities within the participating cities, which are connected globally and meet face-to-face at a week-long global summit every year. In 2018, exactly 20 years after Neil Gershenfield's class on "How to make almost anything" the publication of *Fab City: Mass distribution of (almost) everything* has been launched, presenting best practices from the existing network including digital technologies such as blockchain and artificial intelligence (Diez, 2018). The project is embedded in the widely disseminated imagination of a "new industrial revolution". During the development of the project, its promoters were able to make it appear as an alternative to the smart city model, while retaining some of the latter's attractions, particularly those related to new digital technologies (Rumpala, 2018). These technologies are still considered a driver for change, though in such a way that the population can appropriate them more. Emerging as a sort of counter-narrative in response to top-down smart urbanization efforts, Fab City favors open and loosely coupled coordination systems associated with the empowerment of people to 'democratize' production and gaining back power over local production and consumption practices.

In the following section I will discuss three major foundations of the Fab City approach against existing (theoretical) findings: the re-appropriation of a city's productive function through its citizens, the reorganization of material and informational flows, and the relation between production and consumption in the suggested model.

## 3.4 Reorganizing the Space of Flows: A Cosmo-Local Approach to Urban Industrial Spaces

Fab City expands the model of fab labs that constitute the basis of an alternative model of urban functioning (Rumpala, 2018, 2023). Therein, production is "returned" to the city level, close to its inhabitants, with the promise to being able to provide some basic needs, notably through open manufacturing workshops or small-scale production sites located in the neighborhoods, which put relatively advanced digital machines at the disposal of local communities. Proponents of the Fab City approach promote a city in which citizens (once again) become manufacturers and take possession of their own needs, reclaiming technologies collaboratively and contributing to the control and coordination of various flows (i.e., material, energy, information) which determine urban ecological situations. Thus, in the production system outlined, production is approached from an angle that favors territorial proximity bringing it back to the inhabitants of neighborhoods and adapt it to local consumption and demands. Tomas Diez associates the image of local production as it was present in medieval times with this model – but in a renewed version, jointly connected to global networks of knowledge and immaterial exchanges (Diez, 2017). Fab City suggests the resurrection of the productive function that constitutes a city, but in a form that the population is able to re-appropriate. In doing so, it tends to detach new opportunities linked to digital technologies from their economic and commercial dimension, instead focusing more on the capacities given to its inhabitants. Hence, instead of considering market mechanisms as a main vehicle for economic activity, it stresses the qualities attributed to fab labs (i.e., creativity, incentives to share, productive capacity, open spaces for knowledge exchange etc.) and aims to transpose them to the scale of the city and its territory (Rumpala, 2018).

Consequently, the Fab City approach aims at a fundamental transformation of a city's metabolism through a reconfiguration of exchanges and a reconfiguration of the socio-technical framework that organizes collective life on an urban scale. In this internal logic, the reorganization of flows is mainly enabled by making resources for urban functioning (e.g., technological capabilities) available in the urban fabric. Citizens are involved in a way that they can contribute to the production of what they consume in a relocalized, decentralized, distributed and self-sufficient productive system. The suggested productive system is mainly based on the principles of "design global, manufacture local (DGML)":

> "DGML describes the processes through which design is developed, shared and improved as a global digital commons, whereas the actual manufacturing takes place locally through shared infrastructures with local biophysical conditions in mind." (P2P Foundation, n.d.)

The main ideology and vision behind cosmo-localist approaches to value creation (and, more particularly, manufacturing) is the reduction of global circulation and movement of material goods (i.e., atoms) by simultaneously enabling or facilitating the international circulation and transfer of designs, ideas and knowledge (i.e., bits) on the local realization and production of these ideas – as reflected in the PITO-to-DIDO (product in, trash out vs. data in, data out) model suggested by the Fab City project (Diez, 2016). Hence, in the core of this approach lies the conjunction of open source, open design and production logics at the global scale with local-network production capabilities at a regional scale (Kostakis et al., 2015). In other words, in this conception, material production, controlled locally, remains in the city, and imports as well as exports subsist mainly in informational form (exchanges are then constituted of bits rather than atoms, as summarized in the image also popularized by Neil Gershenfield).

The **image of an auto-productive cosmo-local city** suggested here, reflects a very strong orientation of (re)apprehending the city through its flows as in former conceptualizations of Castells' Informational City developed a couple of decades ago (Castells, 1991b). However, the integration of other (especially environmental) considerations has contributed to a further evolution of the perspective, combining it with that of a self-sufficient city (March & Ribera-Fumaz, 2016). Here, the city is rather imagined as a (biological) organism, an eco-system that has neither clear boundaries nor is it being deterministic, instead it evolves through the interaction with its (natural) environment, stressing the necessity for the circularity of flows.

The reorganization of flows in the cosmo-local productive system considers both incoming and outgoing flows almost as if all activities could be broken down and monitored through that which is put in circulation. Rumpala (2018) has already problematized this simplification of flows because it places the entire urban functioning in the framework of a "circular economy" to escape the negative consequences caused by linear models that rely on imported goods (hence, evading local control), ending up in waste that is costly to manage and without utility. This attention to **material flows** engages in combined reflections on the infrastructures and practices that are associated with them. In this perspective, the city becomes more of a "reservoir of reusable material resources", instead of being condemned to become a giant scrapyard. Waste is considered a valuable resource, as becomes evident in the wide diffusion of circular design approaches in the Fab City movement.

On the other hand, informational flows are not further problematized as long as they can flow freely and contribute to the transfer and creation of "new" knowledge. The main principle for reorganizing informational flows relies on the vision behind what Loveluck (2015) has termed "informational liberalism", which will be introduced and discussed in the subsequent section.

## 3.5 Informational Liberalism, Knowledge Commoning and Collective Consumption

The reorganization of informational flows suggested here, relies predominantly on the imagination of a knowledge society and a rather knowledge-based economy, with the manipulation of symbols, ideas and knowledge becoming the core of the economy (Castells, 1991a). Two aspects are particularly relevant for understanding the rationale behind the productive system suggested by the Fab City project. First, an open-source principle relating to the free flow of knowledge and information; second, the principle of self-organized heterarchies. To understand how they have found their way into conceptualizing the Fab City vision, we need to take a closer look at the history of the Internet and the Free Software movement which have influenced contemporary social hacker cultures. Their core values can be also found in the Fab City manifesto.

Since its early cybernetic beginnings, the Internet has come along with the promise of facilitating the free flow of information, hailed as a tool for democratizing access to information and promoting freedom of expression (Flichy, 2008; Castells, 2002). Due to the specific properties of computer networks that enable alternative forms of power distribution and the coordination of activities by enabling uncoordinated action for coordinated effects (Benkler, 2006). Hence, network computing has been associated with the ability to promote the emergence of **self-organization**. This property is still prominently stressed in recent discourses on "the collaborative economy" and the mobilization of smart crowds related to collective intelligence and collective solutionism. According to Benkler, this central feature is also key to the emergence of what he has termed commons-based peer production, a new modality of organizing production and value creation that relies on the collective sharing, management, and production of resources (Benkler, 2006; Rifkin, 2014).

However, the digitization of information and its circulation via networks have introduced a new dimension of exchanges while concurrently creating a paradox that is still unresolved and present in many current debates on freedom/control problems related to intellectual property regimes (Araya, 2015; Loveluck, 2015). On the one hand, information and data (and even interaction with systems) are increasingly recognized as having a significant economic and political value, as they can be used to generate revenue, influence public opinion, and shape policy decisions. On the other hand, information can be shared and replicated instantly at essentially zero marginal costs regardless of whether it is protected by property rights or copyright laws. In this sense, knowledge is purely non-rivalrous

(Stiglitz, 1999) – meaning that one person's use does not preclude the use by another. Thus, it functions different from other commodities.

Starting with the "New Digital Economy" of the 1990s, for the established laws of economics to remain relevant, legal frameworks were set up trying to protect property rights in the intellectual domain (expansion of patents, licenses, trademarks, etc.). This creation of an artificial scarcity of knowledge and information was perceived to be necessary to ensure the further application of conventional laws of supply and demand to "the goods of the mind" (Loveluck, 2015, p. 9). As a sort of counter movement to prevent knowledge from enclosure, the hacker movement has made valuable contributions to what might be termed "informational liberalism".

One of the most significant achievements of the free software movement founded in the 1980s was the introduction of the legal concept of *copyleft,* turning the existing intellectual property rationale on its head: instead of giving ownership rights to the producer of codes (software), it focuses on usage rights given to consumers/users, including the right to run the software, access its source code, modify the code, and redistribute copies of it, thus building the basis for an informational commons (Weber, 2005) or a commons of the mind (Hess & Ostrom, 2006). This institutional innovation has also inspired many other fields and has most recently been transferred to the production of physical goods (e.g., in concepts such as Open Design and Open Source Hardware). Thus, the key to a linked productive system is that resources within networks are held as common goods (Benkler, 2006; Rifkin, 2014). That is to say, they are collectively shared, managed and produced. This type of productive function obviously demands a sophisticated digital infrastructure for the coordination of flows, engagement of citizens, tracking of material flows, and involvement of micro-contributions from a large cosmo-local network of people. The development of such a (prototypical) digital infrastructure for the productive function of Fab Cities has been recently started in an EU-funded project called "Interfacer". It relies on a federated network/system architecture (i.e., enabling self-organizing heterarchies) and integrates distributed ledger technologies as well as an open-source tool chain that aims to provide functionalities along the entire value flow. Hence, in the image of the cosmo-local city suggested by the Fab City project, the Internet of Things and related advances in digital technologies tend to be seen as another determining, even structuring, factor for the possibilities of exchange and collaboration at a distance and on a large scale (Rumpala, 2018).

In summary, we can observe two different strategies in dealing with the opportunities given by network computing and digitization, or in other words, to organize informational and knowledge flows in a productive urban system. The first one seeks to sustain the classic understanding of market mechanisms and, thus, commodifies information through mechanisms of enclosure. The second – which is the relevant one for the Fab City Project – leverages the specificities of the digital environment to introduce an alternative which, though not necessarily incompatible with the market, thoroughly redefines its boundaries (Loveluck, 2015, p. 13).

As different and partly contradictory as these approaches might be, they all emphasize a liberating force and positive determism that is associated with advances in information and communication technology.

Indeed, the growth of peer-to-peer (P2P) networks leveraging next generation communication, data sharing, and value creation have opened up a broad array of new opportunities for bottom-up civic engagement (Araya, 2015). As Castells (2009) observes, the rise of socially mediated ICTs has sparked new social movements with the capacity to build multi-scale networks across a broad spectrum of socio-political mobilizations This is also reflected in the mobilizations created by the Fab City project resulting in the emergence of a global network of actors disseminating the Fab City vision in very different localities.

Besides considering knowledge as a commons and social good as well as defending the free flow of information on the one hand, while restricting material flows to take place in local cycles on the other; the question that is yet unanswered in detail by the Fab City project is the relation between (knowledge) production and **collective consumption** on an urban scale. The project claims, in order to foster self-sufficiency of cities, "cities need to produce (almost) everything that they consume". In this image "the city" is personified in a way that it is able to produce and consume. Yet, what kind of specific services, goods, and information are collectively consumed in a Fab City? So far, there have been only very few explanations and debates on what exactly should be held in commons (besides knowledge). A lot of emphasis has been put on the actual realization of productive processes and the reorganization of flows or, in other words, on how things come into being and what an alternative urban productive model can look like.

Consumption appears as a rather elusive concept. Following Castells (1978), Dunleavy (2019, p. 1) defines 'consumption' as "the final appropriation of products by people." Indeed, one of Castells' major contributions to urban theory emphasizes the unique status of collectively consumed services (and some goods) often provided by public actors, such as public housing, education, health care, basic infrastructure (from energy, to waste management, streets and water). Collective consumption involves people consuming or using services and other goods of general interest which are particularly subject to the influence of public actors, since their costs are partly or entirely socialized through government subsidies; or their provision is specially regulated to foster social equality; or government agencies organize service provision (Dunleavy, 2019).

Indeed, collective consumption services remain centrally important to urban politics. Social and political polarization around collective consumption (versus private consumption) plays a key role in defining 'the urban' in modern societies, especially in the scope of urban politics (Dunleavy, 2019). The rise of corporately mediated "shared consumption" through platforms such as Google, Uber, Airbnb and the like poses fundamental challenges to the provision of public services. These platforms provide "free" goods and commoditize social interaction itself. Hence, the public sector in cities might become marginalized, if it does not cope with this development integrating it in strategies on urban transformation (Dunleavy, 2019). Though, not only what but also how services are developed and delivered in a city has a significant impact on the quality of life of its inhabitants (especially for manual workers and poorer households apart from intellectual elites). In the context of the Fab City project, this is an important aspect, since all the projects and initiatives evolved under the umbrella of a "Fab City" rely on public funding, and municipal authorities form a central group of stakeholders. So, who should be the final provider of services? And, besides knowledge, what should be held in common? Is it the digital and physical infrastructure (e.g., production means provided in open manufacturing sites) that enables the productive model? What will the process of co-creation emphasized by the movement look like? Those are central questions yet to be answered.

In summary, the principles of informational liberalism (openness and self-organizing heterarchies), outlined at the beginning of the section are closely linked to collective consumption, as both emphasize the importance of collective decision-making and the empowerment of individuals in shaping public goods.

## 3.6 Conclusion and Outlook

Central to these imaginations of a Fab City are four core attributes that relate to aspects of reorganizing informational and material flows, making resources and technologies for productive activities available in the urban fabric and transforming the type of productive system. The **image of an auto-productive cosmo-local city** suggested by the Fab City project reflects a very strong influence of spatial conceptualizations of Castells' Informational City. However, the integration of other (especially environmental) considerations has contributed to a further evolution of the perspective, combining it with that of a self-sufficient city. The city is, hence, rather imagined as an organism, an eco-system that has neither clear boundaries nor is it being deterministic, instead, it evolves through the interaction with its (natural) environment, stressing the necessity for the circularity of material flows. This also leads to the imagination of the city as a reservoir of reusable material resources.

The Fab City model suggests the **re-appropriation of a city's productive function through its citizens**, the co-creative reorganization of material and informational flows integrating the relation between collaborative production and collective consumption practices in a quite original way. In doing so, it tends to detach the new opportunities linked to digital technologies from their economic and commercial dimension, focusing more on the capacities given to its inhabitants. Instead of considering market mechanisms as a main vehicle for economic activity, it stresses the qualities attributed to fab labs (i.e., creativity, knowledge commoning, shared productive means and capacity, etc.) and aims to transpose them to the scale of the city and its territory. Consequently, the Fab City approach aims at a **fundamental transformation of a city's metabolism** through a reconfiguration of exchanges and of the socio-technical framework that organizes collective life on an urban scale.

The prior analysis has shown that the Fab City project emerged into a strategy that aims to redistribute the power of monitoring and control over a territory 'by democratizing advanced technology and enabling networking of users in a digital space.' As a result, it has grown into an initiative that aims to redefine common grounds for citizenships enabled by technology (Rigobello & Gaudillière, 2019, p. 2). Not limited to technological issues, the project is thus at the junction of themes that have taken an increasing place on urban agendas: resilience (i.e., via becoming auto-productive), reasonable use of resources and the limitation of ecological nuisances (i.e., via reorganizing material flows in productive systems) as well as the appropriation of digital technologies (i.e., via making use of digital technologies for urban and economic governance) creating a new promising framework for self-sufficient cities in the digital age.

However, even if a broad understanding of the discursive content around conceptualizations and imaginations of a Fab City helps us link it to reflections and practices developed by the actors that promote it, many of the proposals and arguments spawned here are linked to broader socio-political objectives and strategies pursued in often constrained spaces and idiosyncratic socio-political contexts that might "translate" the suggested model differently. These place-making practices and this place-based struggle for meaning and local solutions will be of particular interest for any future research on Fab Cities in the field of social sciences. Another focus should be on non-human intelligence with its rapidly growing capacities for reasoning and decision-making. In this sense, AI is part of its own self-fulfilling narratives which are now beginning to be felt and experienced in our daily lives. As Picon argues, the imagination of the city as a space of flows and the "monopoly held on urbanistic thinking" regarding urban networks and the flows they produce is beginning to weaken (Picon, 2018, p. 272). Instead, he suggests to imagine the future smart city rather as a city of "occurences and events" as the primary material of the process of reading and rationalizing the urban environment. It is occurrences and events as the actual manifestation of flows in a specific point in time and space that are the basis for human experiences. And after all, it is still people that *make* the city.

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# 4 Lokale Produktion als Beitrag zu einer nachhaltigen Wertschöpfung

## Handlungsfelder und Schlüsselfaktoren für eine erfolgreiche Implementierung

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### 4.1 Einleitung

Das Handeln des Menschen hat im gegenwärtigen Zeitalter bereits „irreversible Auswirkungen auf die geologischen, atmosphärischen und biophysikalischen Prozesse des Planeten" (Weber & Stuchtey, 2019, S. 11). Aufgrund dieser Entwicklung erweitern sich in diesem Jahrhundert die klassischen Zieldimensionen industrieller Wertschöpfung (Kosten, Zeit, Qualität) um die der Nachhaltigkeit (Larsson, 2018). Gegenwärtige Forschungsinitiativen zur Förderung einer nachhaltigen Wertschöpfung sind bisher sehr stark auf die Steigerung der Effizienz von Wertschöpfungssystemen zur Reduktion des Ressourcenverbrauchs ausgerichtet. Allerdings sind diese Maßnahmen aufgrund der steigenden Konsumentennachfrage in ihren Auswirkungen begrenzt, da Effizienzgewinne durch steigende Ausbringungsmengen kompensiert und letztlich die ökologischen Belastungen nicht in dem notwendigen Maße reduziert werden können. Die schrittweise Realisierung der Prinzipien einer **Circular Economy** ist unabdingbar, um die gegenwärtigen Herausforderungen zur Reduktion von Treibhausgasen, den Erhalt der Biodiversität, Schutz verbleibender natürlicher Landflächen und die Förderung der individuellen Teilhabe zu bewältigen (Srai et al., 2016).

Die Entstehung lokaler Märkte (Larsson, 2018) und die damit verbundene Förderung einer lokalen Produktion stellen zentrale Ansatzpunkte auf dem Weg zu einer Circular Economy dar (Srai et al., 2016). Lokale Produktion bietet erhebliche Potenziale, die dafür notwendige Transformation zu fördern, da sie zur Verkleinerung der Wertschöpfungskreisläufe beiträgt (z. B. vereinfachte Rückführung von Rohstoffen und Bauteilen in Wert-

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schöpfungskreisläufe, Vermeidung von Überproduktion, Reduzierung von Transport, Einbindung regionaler Akteure) (Krenz et al., 2022a; Srai et al., 2016; Stahel, 2013). Durch den Einsatz moderner Produktionstechnologien (z. B. additive Fertigung, mobile Produktionseinheiten) und der Digitalisierung des Produktentstehungsprozesses wird eine Produktherstellung für variierende Skalen, die sich lokalen Rahmenbedingungen und Bedarfen anpasst, gefördert (Halverson & Sheridan, 2014; Lentes et al., 2018; Matt et al., 2015; Srai et al., 2016).

Aktuelle Studien und Arbeiten führen verschiedene Merkmale bzw. Eigenschaften lokaler Produktion an. Diese umfassen die Produktion von Gütern für und am Ort des Bedarfs, aber ebenso den Einbezug regionaler Akteure sowie die Verwendung lokaler Ressourcen (Moreno & Charnley, 2016; Srai et al., 2016) Daraus folgt, dass lokale Produktion drei Dimensionen beinhaltet (Krenz et al., 2021)

1. Produktherstellung am Ort des Bedarfs,
2. Nutzung bzw. Einbezugs lokaler Ressourcen in die Produktionsprozesse (Maschinen, Akteure, Materialien)
3. Ausrichtung der Produktherstellung auf die Erfüllung lokaler Bedürfnisse.

Lokale Produktion vermag dabei vielfältige Formen anzunehmen. Sie zeigt sich bspw. in Wertschöpfungsclustern, die Kompetenzen entlang regionaler Wertschöpfungsketten bündeln und in der die Unternehmen ein wettbewerbsfähiges Konsortium auf globalen Märkten bilden (z. B. Hamburg Aviation, Life Science Nord). Ebenso fördern globale Konzerne Formen lokaler Produktion, indem sie endproduktnahe Schritte der Wertschöpfungskette am Ort des eigentlichen Bedarfs umsetzen, um regionaler Kundenbedürfnisse zu befriedigen (z. B. regionale Produktherstellung durch Coca-Cola) Das Handwerk und regionale Gewerbebetriebe stellen ebenfalls eine Form lokaler Produktion dar, welche in kleineren Serien Bedarfe der Kunden vor Ort individuell adressiert. Lokale Maker-Communities und FabLabs repräsentieren eine weitere Form lokaler Produktion, die durch die Partizipation des Individuums und den wechselseitigen Wissensaustausch sowie kooperative Produktherstellung in lokalen, offenen Werkstätten geprägt ist (Krenz et al., 2022a). Diese stark partizipative Form lokaler Produktion ist damit ein entscheidendes Element für Fab Cities.

Wie oben bereits erwähnt, genügt es für die Erreichung langfristiger Nachhaltigkeitsziele nicht, sich allein auf die Einsparung von Ressourcen zu fokussieren. Stattdessen muss eine nachhaltige Produktion alle drei Säulen der Nachhaltigkeit berücksichtigen. Hierzu gehören neben der ökologischen auch die soziale und die ökonomische Nachhaltigkeit.

Ökologische Nachhaltigkeit beinhaltet dabei sowohl das Einsparen von Ressourcen als auch den darüberhinausgehenden Schutz der Natur (z. B. durch den Verzicht auf schädliche Substanzen) (Deutscher Bundestag, 1998). Soziale Nachhaltigkeit wiederum verfolgt das Ziel, den Menschen eine möglichst hohe Lebensqualität zu ermöglichen, was soziale Teilhabe und Chancengleichheit einschließt (vgl. ebd.). Ökonomische Nachhaltigkeit bezieht sich auf den langfristigen Aufbau von Geschäfts- und Unternehmensstrukturen, die Beschäftigungssicherheit und stabile Preise gewährleisten. Alle drei Säulen sind dabei miteinander verbunden (vgl. edb.).

## 4.2 Forschungsmotivation und Vorgehen

Bislang existierende Fälle lokaler Produktion fokussieren sich i. d. R. auf einzelne der genannten Dimensionen lokaler Produktion ((1) Produktherstellung am Ort des Bedarfs, (2) Nutzung bzw. Einbezug lokaler Ressourcen in die Produktionsprozesse, (3) Ausrichtung der Produktherstellung auf die Erfüllung lokaler Bedürfnisse). So bündeln z. B. regionale Wertschöpfungscluster räumlich die Kompetenzen und Ressourcen, aber die Produktion erfolgt für einen überregionalen oder globalen Markt (z. B. Hamburg Aviation in der Metropolregion Hamburg). Das bedeutet zumeist auch, dass das Nachhaltigkeitspotenzial lokaler Produktion nicht vollständig genutzt wird. Lokale Wertschöpfungsmuster, die gleichermaßen auf die Produktion vor Ort unter Nutzung bzw. Einbezug lokaler Ressourcen, zur Erfüllung regionaler Bedarfe ausgerichtet sind, bilden nur einen geringen Anteil der Wertschöpfung im Sektor der Produktion ab. Dabei würde erst die Kombination dieser drei Dimensionen die zuvor genannten Potenziale lokaler Produktion umfassend zur Entfaltung bringen, da sich die Merkmale wechselseitig begünstigen (z. B. Produktion am Ort des Bedarfs fördert den Einbezug lokaler Akteure, die Nutzung lokal verfügbarer Materialien kombiniert mit einer Produktion am Ort des Bedarfs reduzieren Transportwege sowohl für Rohstoffe und Komponenten als auch für das Produkt) (Krenz et al., 2022a).

Dieser Beitrag soll aufzeigen, wie lokale Produktion gefördert werden kann, die allen drei Dimensionen genügt und inwiefern dies in ihrem Zusammenspiel einen Beitrag zu einer nachhaltigeren Produktion leisten kann. Hierzu werden Handlungsfelder identifiziert, die dabei helfen, eine lokale Produktion, die der Produktion am Ort des Bedarfs für den lokalen Bedarf und unter Verwendung lokaler Ressourcen entspricht, aufzubauen. Darüber hinaus wird gezeigt, inwieweit das Agieren innerhalb dieser Handlungsfelder Nachhaltigkeitseffekte erzielen kann.

Zur Herleitung der Handlungsfelder werden Ergebnisse aus vorangegangenen Studien herangezogen, die im Rahmen des dtec.bw-Projektes „Digitale, urbane Produktion“ erarbeitet wurden. Hierfür wurde zunächst eine Meta-Synthese durchgeführt, die das Ziel hatte, die Schlüsselfaktoren einer lokalen Produktion zu identifizieren (Krenz et al., 2022a). Grundlage hierfür waren Texte zu den Konzepten Distributed Manufacturing, Re-Distributed Manufacturing und Lokale Produktion. Im Anschluss daran wurden in Anlehnung an die Sensitivitätsanalyse nach Vester (Vester, 1991) die Interdependenzen zwischen den Faktoren mithilfe eines Wirkungsmodells ermittelt und die Relevanz der Faktoren für die Entstehung von Formen lokaler Produktion analysiert (Krenz et al., 2022a). Auf der Grundlage dieses Modells konnten letztendlich mithilfe eines systemtheoretischen Ansatzes gesellschaftliche Einflussbereiche herausgearbeitet werden, in denen Maßnahmen (entsprechend der Schlüsselfaktoren) umgesetzt werden können (Krenz et al., 2022b). Die zentralen Ergebnisse dieser Arbeiten werden in den folgenden zwei Abschnitten skizziert, um anschließend Handlungsfelder zur Implementierung einer lokalen Produktion herausstellen zu können und im Zuge dessen aufzuzeigen, wie dies zu einer nachhaltigeren Produktion beitragen kann.

## 4.3 Kernmerkmale und Schlüsselfaktoren lokaler Produktion

Im Rahmen der Meta-Synthese zur Analyse der Schlüsselfaktoren lokaler Produktion wurde der wechselseitige Einfluss technologischer, wirtschaftlicher und gesellschaftlicher Faktoren auf die Ausprägung der Dimensionen lokaler Produktion untersucht. Das Ergebnis der Analyse wird nachfolgend dimensionsweise beschrieben. Es zeigt, welche Faktoren entscheidend sind, um eine lokale Produktion zu implementieren.

### 4.3.1 Produktion am Ort des Bedarfs

Die Dimension Produktion am Ort des Bedarfs beschreibt die räumlich konzentrierte Herstellung der Produktion in unmittelbarer Nähe zum Konsumenten (Ort der Nachfrage). Abb. 4.1 zeigt die wichtigsten Einflussfaktoren auf die Produktion am Ort des Bedarfs.

Die **Produktion am Ort des Bedarfs** wird maßgeblich bestimmt durch die Wirtschaftlichkeit lokaler Produktherstellung. Durch die Reduktion des potenziellen Absatzmarktes auf den lokalen Raum steigt die Relevanz einer kosteneffizienten Fertigung kleiner Serien und die räumliche Konzentrierung der Nachfrage (durch Urbanisierung) (Moreno et al., 2017; Pearson et al., 2013). Steigende Kosten für Flächen im urbanen Raum (Erbstößer,

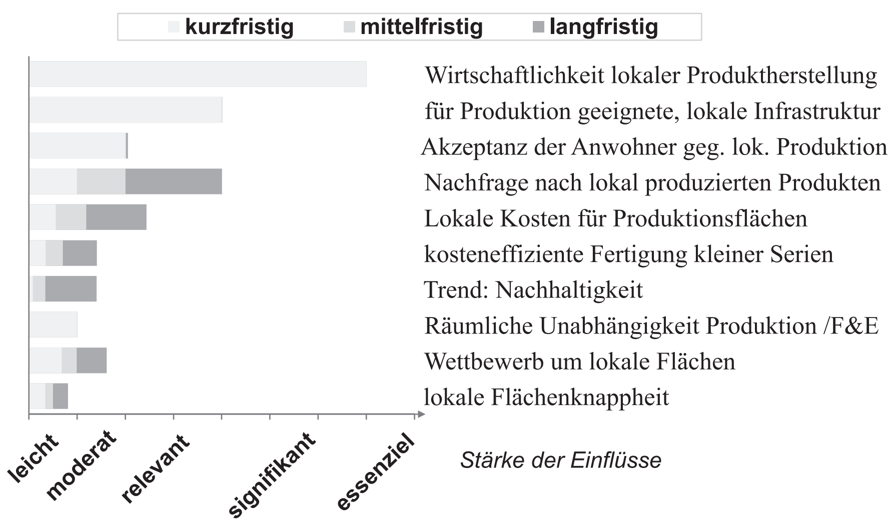


**Abb. 4.1** Die 10 wichtigsten Einflussfaktoren auf die Produktion am Ort des Bedarfs

2016; Lentes, 2016; Sassen, 2009) haben einen negativen Einfluss auf die Wirtschaftlichkeit lokaler Produktion. Der gesellschaftliche Wertewandel, der durch eine Tendenz zu nachhaltigem Konsum geprägt ist, vermag die steigende Nachfrage nach lokal gefertigten Produkten (Läpple, 2013; Matt et al., 2015) zu befördern. Wesentliche Voraussetzungen für die Entstehung einer Produktion vor Ort, bestehen in der Verfügbarkeit einer geeigneten, lokalen Infrastruktur für die Produktion (Erbstößer, 2016) sowie der Akzeptanz der Anwohner gegenüber der Produktion vor Ort (Schössler et al., 2012).

### 4.3.2 Nutzung bzw. Einbezug lokaler Ressourcen

Die Einflüsse auf die Dimension „Nutzung bzw. Einbezug lokaler Ressourcen" werden in Abb. 4.2 dargestellt. Sie umfasst zwei wesentliche Kernmerkmale: die Verwendung lokaler Rohstoffe und Materialien sowie die Einbindung regionaler Akteure (Unternehmer und Arbeitnehmer).

Die **Verwendung lokaler Rohstoffe und Materialien** in lokalen Wertschöpfungskreisläufen wird insbesondere durch die (unzureichende) Verfügbarkeit regionaler Ressourcen und die Möglichkeiten zur wirtschaftlichen Gewinnung sowie Verarbeitung lokaler Ressourcen bestimmt (Recycling und Remanufacturing) (Lowe, 2019; Pearson et al., 2013; Srai et al., 2016). Ebenso können die Risiken und Kosten einer globalen Logistik die Nutzung lokaler Ressourcen befördern. Steigende Entsorgungskosten und Rohstoffpreise, die konsequente Anwendung nachhaltiger Designprinzipien (Lowe, 2019), die Modularisierung von Produkten (Matt et al., 2015) sowie eine verbesserte Transparenz entlang der

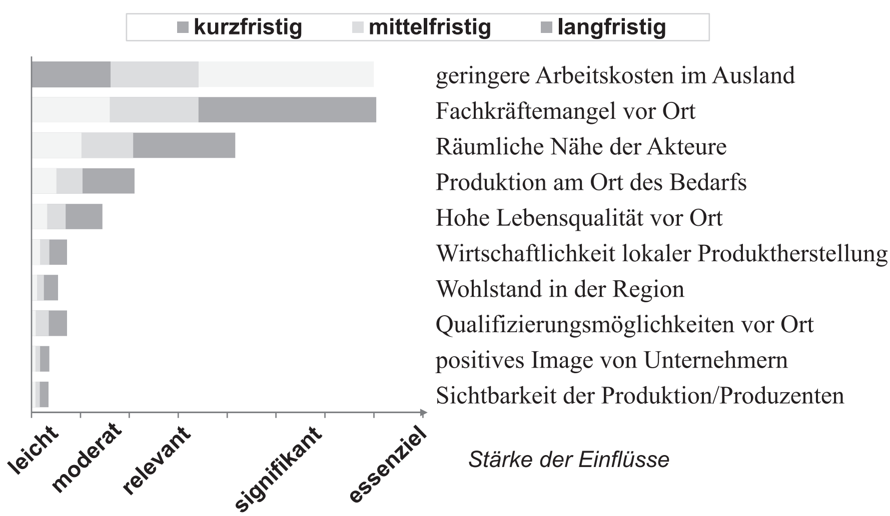


**Abb. 4.2** Die 10 wichtigsten Einflussfaktoren auf die Umsetzung der Produktion durch lokale Akteure (links) und die 10 wichtigsten Einflussfaktoren auf die Verwendung lokaler (Roh-)Materialien (rechts)

Wertschöpfungskette und entlang des Produktlebenszyklus (Yakovleva et al., 2019) fördern die Bedeutung des Recyclings sowie des Remanufacturings für die Nutzung lokaler (Roh-)Materialien im Rahmen der lokalen Wertschöpfung. Auch der Trend zu mehr Nachhaltigkeit (Läpple, 2013) und das sich dadurch verändernde Konsumentenverhalten können dazu führen, dass die Kunden die Nutzung lokaler Rohstoffe bzw. Wiederverwendung lokal verfügbarer Ressourcen einfordern. Die **Umsetzung der Produktion durch lokale Akteure** wird insbesondere durch die zumeist höheren regionalen Arbeitskosten gegenüber dem Ausland bestimmt (Matt et al., 2015; The Government Office for Science, London, 2013). Dieser Faktor verliert durch die Angleichung von Arbeitskosten und Ansätze der gesetzlichen Regulierung zur Durchsetzung von Standards entlang der Wertkette (z. B. Lieferkettengesetz) zukünftig an Relevanz. Hinderlich wirkt hingegen ein Fachkräftemangel vor Ort auf die Umsetzung der Produktion durch lokale Akteure (Busch et al., 2020; Schössler et al., 2012).

### 4.3.3 Ausrichtung der Produktherstellung auf die Erfüllung lokaler Bedürfnisse

Lokale Produktion eignet sich dafür, lokal auftretende Bedürfnisse zu erfüllen, da sie in räumlicher Nähe zu den Nutzenden stattfindet. Dies erreicht sie zum einen durch die Herstellung **individualisierter bzw. lokal angepasster Produkte**, die auf die Bedarfe der Kunden vor Ort ausgerichtet sind (z. B. in Bezug auf Funktion, Design). Zum anderen erleichtert eine **On-Demand Produktion**, auf die lokale Nachfrage kurzfristig und in der gewünschten Menge zu reagieren. Welche Einflüsse hierfür entscheidend sind, wird in Abb. 4.3 dargestellt.

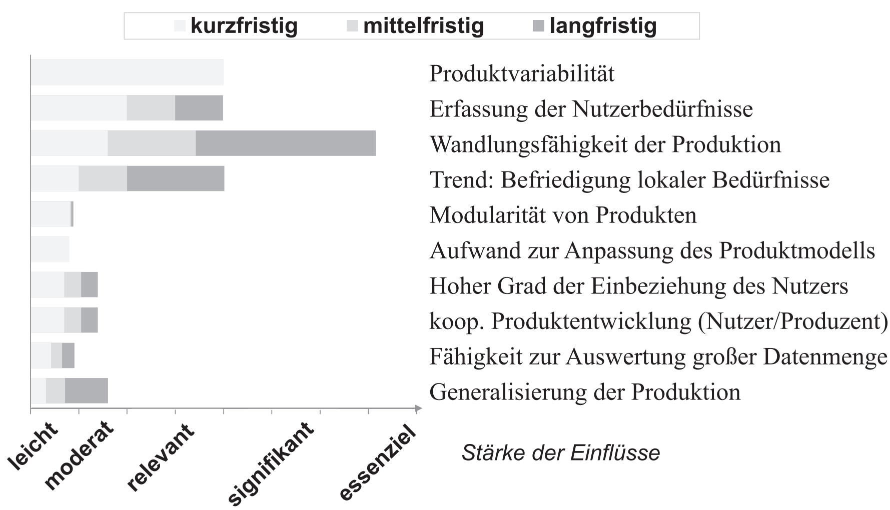


**Abb. 4.3** Die zehn wichtigsten Einflussfaktoren auf On-Demand-Produktion (links) und die zehn wichtigsten Einflussfaktoren auf die Produktion von individualisierten Produkten (rechts)

Die Wandlungsfähigkeit spielt hierbei eine entscheidende Rolle (Lowe, 2019), da sie hilft, den immer schneller wechselnden Bedürfnissen der Nutzenden zeitnah zu entsprechen. Entscheidend hierfür sind außerdem hoch flexible Produktionstechnologien (Pearson et al., 2013; The Government Office for Science, London, 2013), die Generalisierung der Produktion, und der vermehrte Einsatz modularer Produktstrukturen (Lentes et al., 2018). Auch die funktionale Variabilität und Modularität (z. B. durch Softwareanpassungen) sowie Skalenvariabilität der Produkte fördern die Wandlungsfähigkeit lokaler Wertschöpfungssysteme (The Government Office for Science, London, 2013). Die lokalen Bedarfe der Nutzenden zu kennen, wird durch neuartige und sich stetig weiter verbreitende Kooperationsansätze (z. B. Co-Creation, Co-Design) (Kohtala, 2015; Petrulaityte et al., 2017) und die erweiterte Fähigkeit zur Auswertung großer Datenmengen beeinflusst (Data Mining, Künstliche Intelligenz) ermöglicht (The Government Office for Science, London, 2013). Auf der Seite der Konsumierenden wirkt der Wunsch nach individuellen und sofort verfügbaren Produkten als Treiber für eine bedarfsorientierte, Ad-hoc Produktion in lokalen Kontexten. Die Raumknappheit und die damit verbundenen Lagerkosten, insbesondere in städtischen Gebieten, haben ebenfalls einen wichtigen Einfluss auf die On-Demand-Produktion.

## 4.4 Zentrale Handlungsfelder innerhalb der gesellschaftlichen Subsysteme

Die genannten Ausführungen haben gezeigt, welche Faktoren entscheidend für die Implementierung und das Funktionieren einer lokalen Produktion sind. Allerdings können diese nicht beliebig und ohne weiteres variiert werden. Vielmehr sind diese Faktoren in das gesellschaftliche Wirkgefüge eingebettet und liegen im Handlungsbereich verschiedener Subsysteme (Krenz et al., 2022b). Im Rahmen einer Studie zur Systematik lokaler Produktion wurden die Einflusssphären der gesellschaftlichen Subsysteme Politik und Recht, Wirtschaft, Produktion, Wissenschaft und Konsum im Hinblick auf die Dimensionen und Schlüsselfaktoren analysiert. Abb. 4.4 zeigt das Ergebnis dieser Untersuchung und die resultierenden Einflusssphären auf lokale Produktion. In der Abbildung ist deutlich zu erkennen, dass sich die Einflusssphären der gesellschaftlichen Subsysteme für die verschiedenen Dimensionen zum Teil sehr deutlich unterscheiden.

Aus den Ergebnissen der genannten Studien lassen sich nun Handlungsfelder der gesellschaftlichen Subsysteme ableiten, die zentral sind, um eine lokale Produktion zukünftig effektiv zu fördern. Diese betreffen in unterschiedlichem Maße die drei Dimensionen lokaler Produktion, wie nachfolgend dargestellt wird.

Das Politik-/Rechtssystem sowie das Wirtschaftssystem schaffen den Rahmen durch politische Entscheidungen und entsprechende Gesetze sowie daraus resultierende Investitionsentscheidungen für lokale Produktion (Mistry & Byron, 2011; Schössler et al., 2012). So können sie durch Maßnahmen zur Förderung der Fachkräfteverfügbarkeit (z. B. Gesetzgebung zur Zuwanderung, Aus- und Weiterbildung) sowie Maßnahmen zur

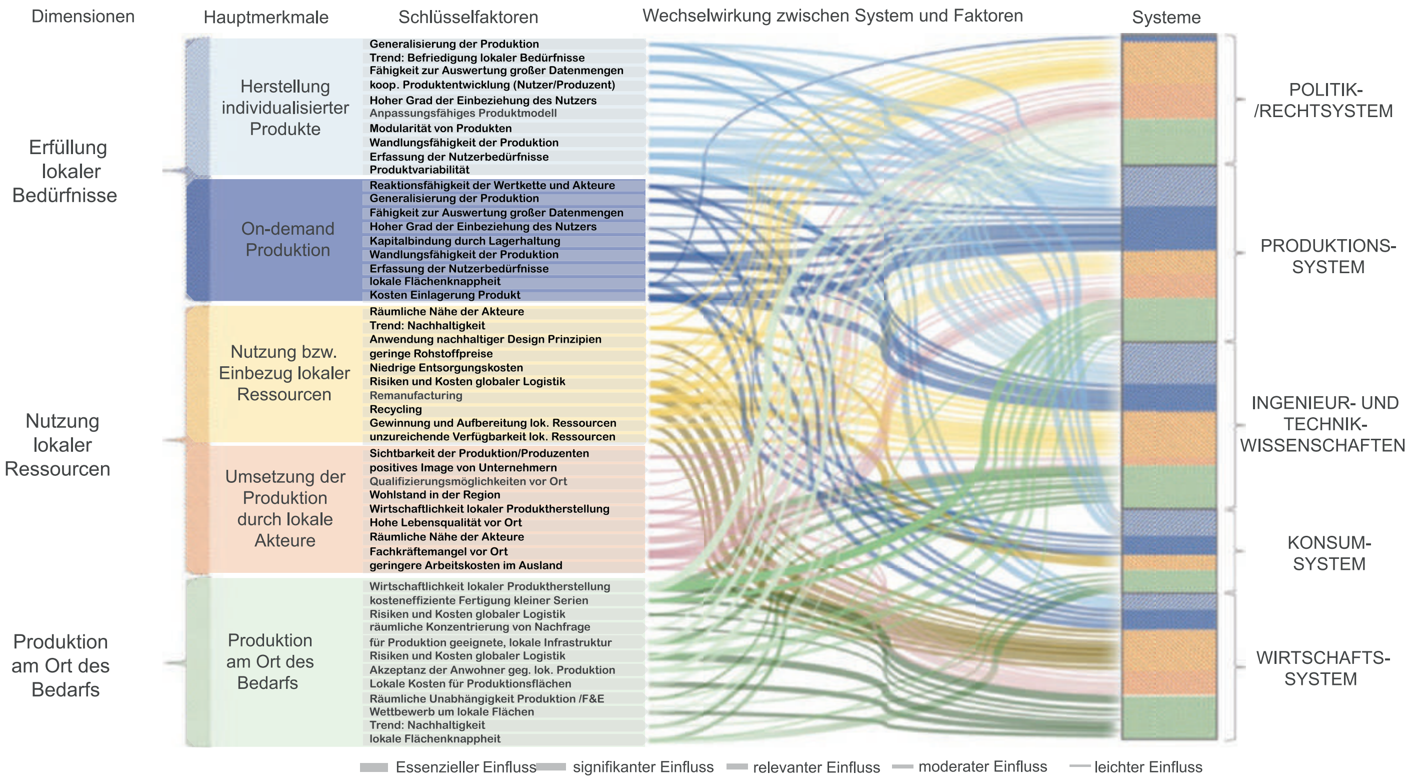


**Abb. 4.4** Zuordnung der Schlüsselfaktoren der lokalen Produktion zu den Einflusssphären der gesellschaftlichen Teilsysteme

Angleichung der Wettbewerbsbedingungen zwischen lokalen und globalen Produktionsstandorten (z. B. Lieferkettengesetz) dafür sorgen, dass regionale Arbeitskräfte zur Verfügung stehen (Schössler et al., 2012; Läpple, 2013; Schrock & Wolf-Powers, 2019). Auch die Verwendung lokaler Rohstoffe und Materialien ist sowohl an rechtliche Rahmenbedingungen als auch die Wirtschaftlichkeit dessen gebunden (z. B. in Gesetzen wie des Emissionsschutzgesetzes, Gesetzen zur Umweltverträglichkeitsprüfung, Bundesnaturschutzgesetz, Verordnung über die Registrierung, Bewertung, Zulassung und Beschränkung chemischer Stoffe etc.). Die Bereitstellung von Flächen für die lokale Produktion sowie der Aufbau einer lokalen Logistikinfrastruktur (z. B. über Bau- und Straßennutzungsrechte sowie Investitionsförderungen) ermöglichen es überhaupt erst am Ort des Bedarfs zu produzieren (Schössler et al., 2012; Fuchs et al., 2017; Erbstößer, 2016).

Während also die Handlungsfelder der Politik sowie das Rechts- und Wirtschaftssystem vor allem in den Dimensionen Einsatz lokaler Ressourcen und Produktion am Ort des Bedarfs liegen, befinden sich die der Produktion sowie Ingenieur- und Technikwissenschaften in den Dimensionen Produktion am Ort des Bedarfs sowie der Produktion für den lokalen Bedarf (siehe Abb. 4.4). Denn gerade neue Technologien und Fertigungskonzepte ermöglichen eine emissionsärmere und raumeffizientere Produktion, sodass die Produktion auch in der Nähe zu Wohnräumen möglich ist (Schössler et al., 2012; Läpple, 2013; Erbstößer, 2016; Lentes, 2016; Burggräf et al., 2019; Juraschek et al., 2017). Die Entwicklung wandlungsfähiger Konzepte sowie die Auswertung großer Datenmengen kann wiederum helfen, die Bedarfe lokaler Akteure zu antizipieren, diese mit den vorhandenen lokalen Ressourcen abzustimmen und daraufhin entsprechend anzupassen (Zaki et al., 2017). Technologien und Strukturen mit dem Ziel einer Öffnung der Entwicklungs- und Produktionsprozesse (Co-Creation, Prosuming) tragen ebenfalls dazu bei, denn durch die Interaktion zwischen den Akteuren können Nutzende ihre Bedürfnisse leichter in die Produktion einbringen (Kohtala, 2015). Ebenso können in offeneren Wertschöpfungssystemen lokale Akteursgruppen gemeinsam produzieren (z. B. in Makerspaces oder FabLabs) (Schrock & Wolf-Powers, 2019). Es liegt somit auch in der Hand der Produktions- sowie Ingenieur- und Technikwissenschaften, die Nutzung lokaler Ressourcen zu ermöglichen.

Das System Konsum kann zuletzt durch seine Nachfrage sowohl die Dimension Produktion am Ort des Bedarfs als auch die der Nutzung lokaler Ressourcen stärken. Die Nachfrage nach Produkten, die lokal produziert wurden, z. B. durch den Einsatz lokaler Rohstoffe oder Arbeitskräfte, ist die Voraussetzung dafür, dass Unternehmen überhaupt am Ort des Bedarfs oder unter Verwendung lokaler Ressourcen produzieren (Schrock & Wolf-Powers, 2019; Läpple, 2013).

Zu beachten ist hierbei, dass die unterschiedlichen Subsysteme in ihren Einflusssphären und Wirkmechanismen miteinander gekoppelt sind, d. h. ihr Wirken bedingt das der anderen. In der Realität sind die Zuweisungen somit weniger strikt, als sie hier erscheinen. So nützen z. B. neue Technologien (z. B. zur emissionsarmen Produktion) nur etwas, wenn diese auch von rechtlicher bzw. staatlicher Seite aus zugelassen werden. Gleichermaßen nützt es wenig, wenn neue Technologien individualisierte oder lokal erzeugte Produkte ermöglichen, diese aber nicht nachgefragt werden. Eine lokale Produktion kann daher nur gelingen, wenn alle Subsysteme in ihren Handlungsfeldern gemeinsam agieren.

## 4.5 Nachhaltigkeitspotenziale lokaler Produktion unter Berücksichtigung der Handlungsfelder

Wie gesehen, berühren die zuletzt aufgeführten Handlungsfelder zur Förderung der lokalen Produktion in den verschiedenen Subsystemen der Gesellschaft alle drei Dimensionen lokaler Produktion.

In Tab. 4.1 ist zu erkennen, wie die Einflusssphären der Subsysteme im Hinblick auf die Kernmerkmale zur lokalen Produktion die drei Säulen der Nachhaltigkeit durch ihre Partizipation an der lokalen Produktion betreffen.

Wenn das **Politik- und Rechtssystem** die infrastrukturellen Voraussetzungen für eine lokale Produktion schaffen, dann kann dies die regional ansässigen Unternehmen stärken (ökonomische Nachhaltigkeit): Etwa, wenn die Stadt Bebauungspläne ändert, um kleine emissionsarme Gewerbebetriebe zuzulassen oder Abstellmöglichkeiten für PKWs in Wohngebieten schafft. Solche Erleichterungen können wiederum das Betreiben lokaler Betriebe erleichtern, was zu neuen Arbeitsplätzen und/oder sicheren Beschäftigungs- und Ausbildungsmöglichkeiten führt (ökonomische und soziale Nachhaltigkeit). Investitionen

**Tab. 4.1** Einflusssphären der Subsysteme auf die Nachhaltigkeit unter der Perspektive der Kernmarkmale zur lokalen Produktion

| | Ökonomische Säule | Soziale Säule | Ökologische Säule |
|---|---|---|---|
| Politik-/Rechtssystem | Ermöglichung lokaler Infrastruktur, Wirtschaftlichkeit von Remanufacturing und Recyclingprozessen | Qualifikationsstrukturen zur Fachkräfteverfügbarkeit, Regelungen zur Angleichung von Arbeitsstandards | Förderung der Rahmenbedingungen von Remanufacturing und Recycling, Angleichung Umweltstandards, Ermöglichung der Nutzung lokaler Ressourcen |
| Produktion/Ingenieur-/Technikwissen-schaften | Technologien zur Erhöhung der Wettbewerbsfähigkeit, der Schaffung von Arbeitsplätzen (z. B. kosteneffiziente Fertigung kleiner Serien, raum-effiziente Technologien) | Verkürzung von Arbeitswegen, Raumarme Fertigung (mehr Raum für soziale Nutzung (z. B. Wohnen oder öffentlicher Raum)), Öffnung der Produktion (Empowerment) | Raumarme Fertigung (z. B. Vermeidung von weiterer Versiegelung von Böden), Emissionsarme Fertigung & Produktion (z. B. Wegfall von Transportwegen), Vermeidung von Überproduktion, Nutzung lokaler Ressourcen |
| Konsum | Unterstützung lokaler Unternehmen durch Kauf lokaler Produkte | Partizipation an der Wertschöpfung (Empowerment) | Nachfrage nach regional hergestellten Produkten |

bei Aus- und Weiterbildung (Errichtung von Berufsschulen oder Qualifikationsprogrammen, die mit lokalen Unternehmen kooperieren, Qualifikationsprogramme) sowie die Anerkennung von Qualifikationen seitens des politischen und Rechtssystems können zudem die Teilhabe und Chancengleichheit der Bevölkerung stärken. Standards und rechtliche Regelungen, die, z. B. das Recyceln und Remanufacturing nicht nur ermöglichen, sondern ggf. vorschreiben, und die auf eine zirkuläre Produktion abzielen, können wiederum einen Beitrag zur ökologischen Nachhaltigkeit leisten.

**Produktions- und Ingenieurwissenschaften** berühren die Säule der ökonomischen Nachhaltigkeit, indem sie smarte und raumsparende Systeme entwickeln. So sparen die Unternehmen z. B. Lagerkosten, ggf. auch Entwicklungskosten durch die Einbindung der Nutzende in die Wertschöpfungsprozesse. Dies ist insbesondere für KMUs (z. B. regionale Handwerksbetriebe) wichtig, um im Vergleich zu den großen global agierenden Konzernen andere Kundensegmente bedienen zu können. Die Einbeziehung der Nutzenden ermächtigt diese zur Mitwirkung an Produktionsprozessen, was als Beitrag zur sozialen Nachhaltigkeit verstanden werden kann. Doch neue, smarte Technologien können nicht nur die Wettbewerbsfähigkeit stärken, sondern auch die Verbindung zwischen Wohnraum und Produktionsort erleichtern, indem sie es ermöglichen, emissionsärmer zu produzieren (wie z. B. durch 3D-Drucker). So kann ein Zusammenleben von Produktion und Wohnen möglich werden, ohne dass die Anwohner Belastungen ausgesetzt sind, wie es noch in Zeiten der Industrialisierung der Fall war, in deren Folge Wohnen und Produzieren räumlich getrennt wurden. Darin liegt eine Chance für die ökologische Nachhaltigkeit (sowohl durch verkürzte Arbeits- und Transportwege als auch in der Emissionsreduktion als solche). Zudem können durch On-Demand-Produktion Überschüsse und damit Ressourcen eingespart werden (Fuchs et al., 2017). Auch sozial betrachtet ist dies ein Vorteil, da die Anwohner kürzere Arbeitswege und dadurch mehr Freizeit erhalten können.

Das **Subsystem Konsum** wiederum kann aufgrund der Nachfrage nach ökologischen, regionalen Produkten ebenfalls alle drei Nachhaltigkeitsdimensionen adressieren. Wenn Verbraucher Produkte aus ihrer Nähe wünschen, stärken sie damit die regional ansässigen Unternehmen, was die regionale Wirtschaft fördert sowie Arbeitsplätze sichert und Transportwege reduziert. Zudem können sie durch die Öffnung der Produktion und die räumliche Nähe zu dieser an der Produktion oder den Produktionsstrukturen mitwirken, was Ihnen mehr gesellschaftlichen Einfluss und Teilhabe (zumindest an Produktionsprozessen) ermöglicht.

## 4.6 Ausblick: Auf dem Weg zu einer lokalen und nachhaltigen Produktion

Insgesamt zeigt sich damit, dass die lokale Produktion, insbesondere sofern sie gleichermaßen am Ort des Bedarfs, für den lokalen Bedarf sowie unter Verwendung lokaler Ressourcen stattfindet, einen umfassenden Beitrag zu einer nachhaltigen Produktion leisten kann. Damit dies gelingt, müssen jedoch die genannten gesellschaftlichen Subsysteme hierzu beitragen. Die aufgeführten Handlungsfelder zeigen dabei an, worin die einzelne Mitwirkung bestehen kann. Aufgrund der Kopplung der Systeme sollte dabei jedoch berücksichtigt werden, dass die Entscheidungen innerhalb einzelner Systeme sich gegenseitig bedingen. Dies kann sowohl in hinderlicher als auch förderlicher Hinsicht geschehen. So können rechtliche Regelungen den Einsatz von Technologien ermöglichen. Allerdings können auch nicht-intendierte Folgen auftreten, wenn beispielsweise die Änderung von Bebauungsplänen, die ein Nebeneinander von Wohnen und (emissionsarmer) Produktion zulässt, den Wettbewerb um Raum erhöhen und sich damit negativ auf die soziale Nachhaltigkeit auswirkt.

Ebensolche nicht-intendierten Folgen sowie das Zusammenwirken der einzelnen Handlungsfelder sollten aus diesem Grund verstärkt inter- und transdisziplinär untersucht werden.

Auch eine lokale Produktion, wie wir sie uns aktuell vorstellen können, wird damit nicht in jeglicher Hinsicht vollständig nachhaltig sein können, zumal sie nicht für alle Produkte geeignet erscheint. Darüber hinaus sind Produkte aus lokaler Fertigung aktuell meist teurer als die in anderen Ländern und größeren Stückzahlen hergestellten. Für eine nachhaltige Produktionspolitik müssten solche Produkte auch für alle gesellschaftlichen Gruppen finanzierbar sein.

Zudem bleibt offen, ob eine vollständige Abkehr von der Massenproduktion sinnvoll erscheint. Sowohl die Umsetzbarkeit als auch die globalwirtschaftlichen Folgen davon sind derzeit nicht absehbar. Die Gefahr bestünde, dass lokale Produktion vor allem für die ohnehin wohlhabenderen Länder eine Option wäre, weil sie sowohl über die technischen als auch qualifikatorischen Ressourcen hierfür verfügen. Ein ganzheitlich nachhaltiger Ansatz muss jedoch ebenfalls oder gerade berücksichtigen, welche Konsequenzen er für die wenigen wohlhabenderen Länder hätte, die aktuell von der Massenproduktion (durch Outsourcing) profitieren.

Die hier beschriebenen Effekte zeigen jedoch, dass sie das greifbare Potenzial bietet, das jetzige System hin zu einer umweltfreundlicheren, teilhabeförderlichen und damit ganzheitlich nachhaltigeren Ausprägung zu transformieren. Mithilfe der skizzierten Handlungsfelder erscheint der Weg zu einer solchen nachhaltigeren lokalen Produktion erreichbar, sofern eine ausreichende Abstimmung der Handlungsfelder und Maßnahmen stattfindet – auch auf globaler Ebene.

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# Teil II

# Governance, Economics, and Enabling Technologies

# 5 Creative Flows

## An Economic Model for Distributed Design and Production

Denis Roio, Micol Salomone and Stefano Lucarelli

## 5.1 The Knowledge Commons

This article is a production-oriented approach to the theoretical context of future knowledge-based economies (Slater, 2005). We profile the application of a new form of economic and social organization for the stewardship of knowledge commons to manage collective knowledge resources and digital infrastructures (Bria, 2019).

On theoretical grounds, our proposal opposes what is known as cognitive capitalism. As argued by different scholars (Vercellone, 2005; Fumagalli, 2010), the starting point of cognitive capitalism is a radical critique of the apologetic vision of the actual mutation entailed by the new liberal theories of knowledge-based economy. In this new stage of industrial capitalism, the central stake of value capturing, and accumulation leads to the privatization of the collective production of knowledge towards the accumulation of a fictitious good as capital. We think such approaches are counterproductive as they move on to strengthen intellectual property rights and consequently drive revenue mechanisms to render artificially rare resources that would otherwise be abundant, such as knowledge and information (Gorz & Salsano, 2003; Lucarelli & Fumagalli, 2008).

As a viable alternative to this sterile evolution of the industrial model (Rifkin, 1996, p. 400) we propose the development of a federation of intensive knowledge communities (Diez, 2012) mostly related to activities linked to the informational revolution, as with the exemplary model of the free software and the copyleft (Stallman, 2002).

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### 5.1.1 Beyond Scarcity and Accumulation

Our stage is that of physical labs whose mission is to innovate local production by means of a federated networking and a shared pool of global knowledge: what may be defined as the counter-infrastructure for an operation of critical empowerment and emancipation in a networked world (Dragona, 2016). This scenario poses a challenge: apply a transparent and participatory budgeting process to the distribution of wealth that needs to be redistributed to all people active in a Fab City (De Paoli et al., 2017), turning the perception of work as the origin of money and wealth from sacrifice (von Braun, 2015) to participation in a commoning process.

Here we suggest an economic model that offers a progression into the context of "free and open source software" (FOSS) towards a more generic dimension that can work both as a community ethos and as an economy (Coleman & Golub, 2008). We will proceed to elaborate on the economic aspect and offer a helpful categorization to reference the economic underpinnings of this model.

To describe the Creative Flows economic underpinning, we'll use Greimas' Semiotic Square (Greimas et al., 1989) as a narratological device to organize four central moments of the knowledge commons lifecycle described as Creation, Appropriation, Sharing and Distribution (Roio, 2018) (Fig. 5.1, "1. Definition").

**Greimas' Semiotic Square** Definition of the knowledge commons lifecycle, the four nouns describing the four moments:

- **Creation** is the inception and realization of digital products.
- **Appropriation** is the adaptation of digital products to a specific context.
- **Sharing** is the circulation of digital products, open to the study by others.
- **Distribution** is the packaging and documentation of digital products.

Arguably industrial powers are historically established by the application of an economic system based on trade secrets and piracy (Ben-Atar, 2008) where values flow counterclockwise through these four moments.

**Modern Industry Implementation** The configuration shown in figure (Roio, 2018) (Fig. 5.1, "2. Modern industry implementation") represents how modern industries implement their business model in a capitalist economy when dealing with immaterial production, for instance, art, entertainment, or software. The **Creation** moment is often branded as "authorship" and deals with the **Appropriation** and author rights management. **Appropriation** is a legal problem where rights are reserved for the producer, while detailed deals may be between the producer and the author. The link between **Creation** and **Appropriation** is not generating value but consolidating an agreement on how **Distribution** follows value creation. The passage between **Appropriation** and **Distribution** is where the proprietary industry generates profits: it distributes packaged products to a large audience of

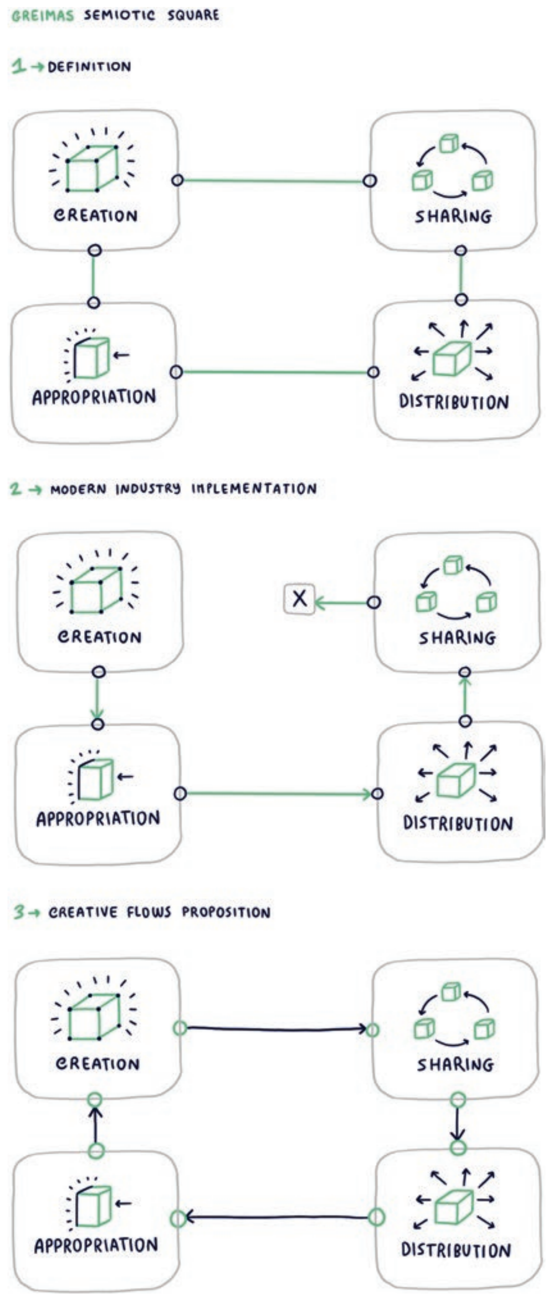



**Fig. 5.1** Greimas Semiotic Square: (1) Definition, (2) Modern industry implementation, (3) Creative Flows proposition

consumers. The products may be material (CD, DVD, mass storage supports, etc.) or immaterial (like online shops and proprietary markets like iTunes, Spotify, etc.).

Further on, there may be different agreements on how the acquired materials can be shared from **Distribution** to **Sharing**. Such contracts may vary in nature and quality of implementation and are often a contested ground since it is in the industry's interest to regulate heavily, to monitor and sanction the violation of restrictions put in place here. To this link belongs the techno/political debate about DRM (Digital Restrictions Management), the right to copy and share with friends, the potential regulation for clubs of people sharing content, and also the way Public Libraries function.

Finally, the link between **Sharing** and **Creation** is broken, with some rare exceptions. Authors are inspired by a shared cultural context (from **Sharing** to **Creation**). Still, in a capitalist economy based on scarcity, authors and industry have a mutual interest in denying this link and blocking most "derivative" works, denying that many "original" works are derivatives of works shared in the wild.

Our objective here is to go beyond this economic configuration and leverage the actual abundance of production and re-production found in free and open-source economies, where the flow turns clockwise, proposing an economic model based on commonfare (Fumagalli et al., 2019).

**Creative Flows Proposition** In this circle shown in figure (Fig. 5.1, "3. Creative Flows proposition") every moment can be the starting point for agencies that focus on the process rather than the result. The ideal starting point is Sharing and is furthest from Appropriation: it represents the space for an assortment of resources to be configured and manipulated in an infinite number of ways, further in the flow, by distributed Creation, Appropriation and Distribution.

The Distribution moment acquires the form of a free and open market where interactions can be structured, traced, and categorized: the precise notarization of historical revisions made on projects by programmers and participants in Fab City networks offers a brilliant example of this. Appropriation thus becomes not a moment for the restriction and management of author rights but brings us back to the meaning of "Appropriate Technology" (Schumacher, 2011) and includes the contextual and distributed agency for translations, adaptations, customizations, and user experience improvements within specific communities.

Creation now follows Appropriation and indicates that the moment of authorship is closely bound to that of appropriated education as an intelligible passage of values between a concrete instance of knowledge and the individual. The individual or collective moment of Creation is less isolated from other moments and, rather than representing the enclosing act of "intellectual property", it highlights that Creation by individuals or collectives depends on a vibrant and resourceful Sharing and adequate and effective Appropriation.

The last closing passage from Creation to Sharing is an economic moment characterized by mechanisms of reputation and curatorial activities intended to facilitate and relate to authors. Sharing is, in fact, crucial to the very existence of authorship.

This study lays down the terminology and general context for describing the free open-source economies praised for their principles of commons-based peer production and virtue (Benkler & Nissenbaum, 2006). This model provides a limited idiolect for its dynamics that we use to define our implementation of Creative Flows.

### 5.1.2 Commoning for Creativity and Balance

> "It is necessary to prescribe beforehand certain definite principles of policy, particularly in regard to the maximum limits of permitted overdraft and the provisions proposed to keep the scale of individual credits and debits within a reasonable amount, so that the system is in stable equilibrium with proper and sufficient measures taken in good time to reverse excessive movements of individual balances in either direction." – J. M. Keynes (1941)

The monetary circuit we are developing assumes recognition not only of collective work but also of positive externalities due to the new knowledge that arises from the creative atmosphere and the sharing of projects in open space. Ongoing activities positively affect each other. Also, a project owes part of its success to the failing attempts at developing other projects in the same beautiful place. Therefore, the value of the work done must also consider the time it takes to establish a creative atmosphere, which we consider a positive externality. If we give a measure to these positive externalities, we will have a chance to recognize the value added by all participants. The need to keep the creative atmosphere alive and to take positive externalities into account leads to the proposal of a transactional scheme organized as Creative Flows.

Incoming amounts paid for a Fab City product go to the common credit account of a clearing house. This will then redistribute these amounts to participants based on the performed activity. Using idea/strength points is instrumental in avoiding accumulation, thus decreasing the transactional potential associated with tokens; there is a cyclical resetting of their value inspired by the demurrage principle. A common internal credit unit (redeemable currency) is created at every cyclical reset.

Each person can decide whether to take these resources and reinvest them in the ecosystem to invent new projects or to redeem them and use them personally. In the likely case of a private company being responsible for the sale and redistribution of products developed by people in a Fab City, it would pay back liquidity to a legal entity (a Fab City association) which would then apply its internal redistributive logic as Creative Flows.

The people participating in the creative activities of a Fab City are also the beneficiaries of a redeemable credit unit. Still, they cannot accumulate the token above a certain threshold, or the principle of demurrage is triggered. The Fab City manages cyclical demurrage (Kennedy & Kennedy, 1995) to become a forced reinvestment above a profit threshold

(Lietaer & Dunne, 2013). The principle of reciprocity in Creative Flows can be expressed as "commoning yields to commoning," believing that only commoning nurtures the creative atmosphere (Teli et al., 2020).

## 5.2 Creative Flows in Fab City OS

In the scope of the INTERFACER[1] project with Fab City Hamburg (Fabcity Foundation, 2016), we took the occasion to render a simple implementation of the Creative Flows economic model we are proposing at an experimental stage. Hence, we consider this implementation a pragmatic appendix to this theory to be adopted and developed in the future, based on the idea of a digital currency that leverages participation and reputation in a peer-production community whose network dynamics (Roio & Beneti, 2018) are functional to the preservation and further development of the common.

We based our current implementation on previous research and development work done on the concept of "Social Proof of Work" in two different EU projects: one focused on "Decentralized Citizen Engagement Tools"[2] (D-CENT H2020/CAPS grant nr. 610349) and the other on "Poverty, Income and Employment News", also known as Commonfare.[3] When we piloted these projects a decade ago (Bassetti, 2019), it was already evident that the technological advancements in cryptocurrency were not aligning with equivalent innovations in economic models. What Bertolt Brecht once named "Umfunktionierung" (Benjamin, 1969 [1935]) seems to us to be a missed opportunity today: we can progress on the socio-economic dynamics linked to technological innovations rather than apply old capitalist models based on scarcity and accumulation.

In practical terms, we based our implementation on the organization of meaningful data and interactions for which the Fab City OS constitutes an advanced accounting system (Fritsch et al., 2021). We organize the record of all exchanges according to a Resource-Event-Agent accounting system (REA; McCarthy, 1982) whose data rests on a Graph database that documents all relationships and offers an easy way to search through them. Then we apply the Valueflows vocabulary (Foster et al., 2017) as one possible semantic organization of this data (see Chap. 8 in this publication: Roio et al., Digital Product Passport). By doing so, we use "points" to the interactions between agents, for instance, the agreed offer and provision of contributions to projects. There are two different kinds points to map two different dimensions in Keynesian economics:

I. Idea points → debt
II. Strength points → credit

[1] Interfacer project EU regional fund, url: https://interfacer.eu
[2] D-CENT H2020/CAPS grant nr. 610349, url: https://dcentproject.eu
[3] PIENews H2020/CAPS grant nr. 687922, url: https://commonfare.net

This configuration (Fig. 5.2) contemplates the existence of agents acting as Entrepreneurs within a network and proposing their "ideas" as possible projects on which the collective (one or more federated Fab Cities) may decide to invest.

Idea points (I., II.) are assigned during the proposal process (Fig. 5.3). The result of this consists of a given credit to ideas that entrepreneurs (named Ada in our illustrations) have developed. This credit is equivalent to Ada's debt to the community and will be used to pay people who can help with the work.

Work takes time, so this process will unfold across a timeline that, when lacking liquidity, creates a risk for entrepreneurs and, consequently, their contracted workers. The collective can overcome this scarcity by applying a monthly calculation of produced or consumed points. Based on this calculation, the collective can give an income to Ada and all those who have consumed or produced a certain number of points, perhaps above a certain established threshold (Fig. 5.4). Once calculated, the strength points can be reset to zero since accumulation does not count in this system: the points only help the collective to account for each person's participation.

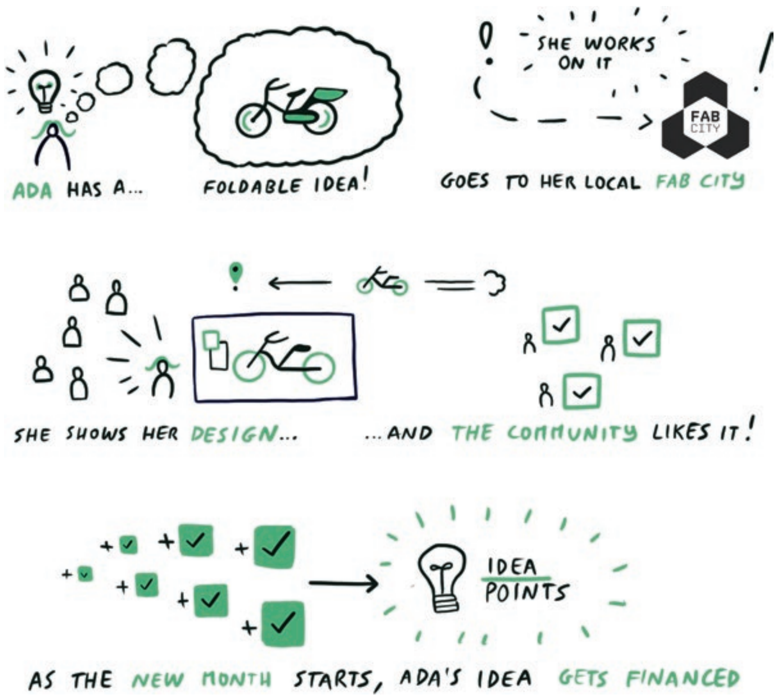
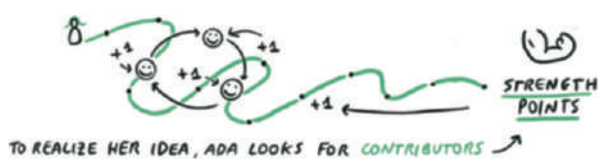



**Fig. 5.2** Initiation of the Creative Flows process

**Fig. 5.3** Creative flow – strength points



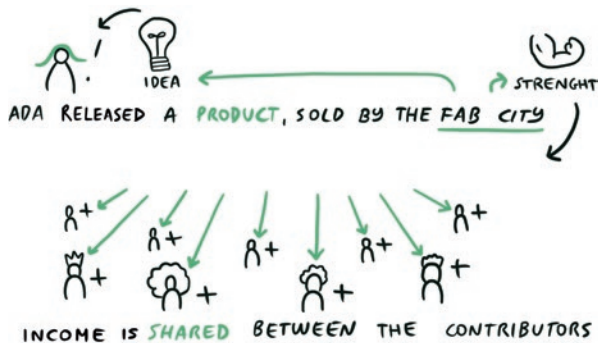



**Fig. 5.4** Creative flow – distributed income

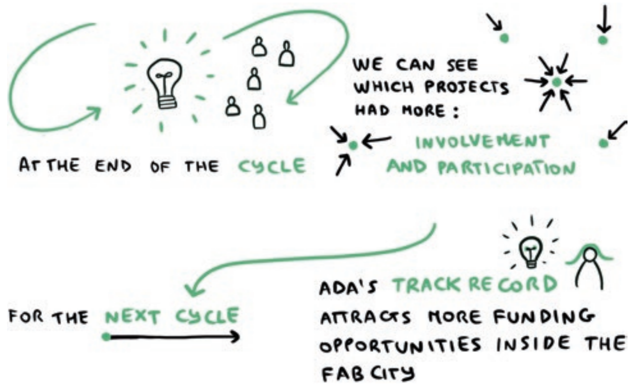



**Fig. 5.5** Creative flow – trace record

This system does not represent its liquidity by points: they are not the money that pays for the participant's time and fuels its economic growth. We may define I. idea and II. strength points in cryptonomics terms as "non-fungible tokens" that are "burned" using a "peg" linking them to an amount of money (or fungible tokens) at the beginning of every new cycle (Fig. 5.5). The pegged value will vary depending on the liquidity available to the collective, and in case of scarcity, it may be mitigated by an existing federation. In any case, the collective administration of this liquidity rate will help the bootstrap of new collectives while keeping a balance with a basic income based on shared savings.

In the graph, we realized this implementation in our Fab City OS software by creating points when certain exchanges take place as approved contributions. The software can then visualize the graph of contributions related to a given project that has taken place within a certain amount of time. Based on that visualization and other flexible data models obtained via GraphQL queries, the collective can decide to assign participants a "social proof of work".

## 5.3 Outlook

There is still room for improvement: this implementation needs piloting on a larger scale to focus on details in particular use cases and automatize many of its calculations. While it was presented in the context of the INTERACER project in Hamburg, participants posed many helpful questions: we addressed only some of them with our current implementation or theoretical answers. Collectives will always need the flexibility to adapt Creative Flows to their production model or service provision dynamics. We are committed to distributing and maintaining our software implementation as free and open-source software and are also ready to offer all necessary technical support for an adoption. Strengthening these experiences can facilitate the transition from the system of ownership and exploitation of collective resources that characterizes cognitive capitalism to a real knowledge-based economy.

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# Transitioning to a Fab City: A Governance Perspective

6

## How Transition Management Can Promote Urban Change: Case Study Hamburg

Anna Wildhack, Jana Koppe and Jörg Knieling

## 6.1 Introduction

Cities and metropolitan regions play host to many proposed solutions to global sustainability challenges and the implementation of the Sustainable Development Goals (SDGs). They are well-suited as real-world experimental sites for investigating and testing system innovations for sustainable change (Schneidewind, 2013). The proximity and localization of actors and the high density of institutional structures in the urban context are key factors in these experiments (Loorbach & Shiroyama, 2016; WBGU, 2016; Wolfram, 2014).

There are numerous efforts at the city level, including joining interregional networks, to meet the challenges of climate change with local strategies and to promote sustainable consumption and production in a circular economy (specifically SDGs 11–13). At the same time, it is evident that progress is too slow and that sustainable development efforts are thwarted by the continued production of unsustainable products and unsustainable consumption (IPPC, 2023). There is growing recognition in sustainability research and debate that global sustainability challenges cannot be addressed by optimizing existing systems in the form of incremental improvements and technological fixes alone: transformative change that addresses the underlying systemic challenges and problems is required (for an overview: Heyen et al., 2018; Köhler et al., 2019).

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In recent decades, transformation studies has emerged as a field of research that focuses on the dynamics of fundamental, long-term societal change (Köhler et al., 2019; Zolfagharian et al., 2019; Geels & Schot, 2010). Transformations are radical changes in the structures, cultures, and practices in a social (sub)system. Transformation science assumes that these transformations cannot be directly controlled, but they can be influenced, promoted, and accelerated (Wittmayer & Hölscher, 2017; WBGU, 2011). To this end, various governance approaches have been developed that aim to understand, analyze, and shape transformation processes toward sustainability (Köhler et al., 2019). This article takes a closer look at transition management as a possible form of governance of transformations/transitions.

The transition management approach has so far been applied mainly to energy (Verbong & Loorbach, 2012), water (Van der Brugge et al., 2005), and mobility (Loorbach, 2022; Avelino et al., 2012). Only recently has it been used to describe governance processes in cities and regions (Roorda et al., 2014; Ferguson et al., 2013; Wittmayer et al., 2014, 2015; Evers et al., 2015) and at the local level (Wittmayer et al., 2014).

The City of Hamburg has been part of the transformation effort 'Fab City' since 2019. In contrast to other city initiatives, which are often limited to sectoral improvements or efficiency enhancement and optimization through new technologies (on smart cities: Rumpala, 2021), the global Fab City initiative calls for a fundamental system change: 'What is at stake? The need to redesign the global system' (Armstrong et al., 2022). Fab City sees itself as a new, comprehensive urban model for transforming and shaping cities and regions toward sustainability (Diez, 2016, 2021).

This fundamental and visionary approach combines bottom-up movement, digitalization, and new interactions and interdependencies between different spatial scales, actors, and resources (glocality) to create new patterns of production and consumption. The basis for this is a circular economy built on open-source exchange in which citizens become prosumers, i.e., designers or producers of goods that are designed globally and consumed locally. By 2054, the goal is to have all of the city's consumer goods produced locally (Diez, 2016; Diez et al., 2018).

In order to implement the goals of the Fab City Global Initiative, Hamburg and other Fab Cities are pursuing two closely intertwined strategies: the establishment of Fab Labs and Makerspaces as local production and experimentation sites, and the network idea, which is primarily based on the principle of sharing and exchanging data, information, knowledge, design and codes in local and global networks and is based on the open-source principle.

This article deals with a central question of all Fab Cities: which methods and strategies can be used to successfully transform a city into a Fab City? Using Hamburg as an example, we aim to illuminate how the transition governance perspective can contribute to understanding and shaping a Fab City. To this end, we first provide a brief overview of the concepts of transition research and the transition management approach, and then elaborate on concrete governance challenges and opportunities using Hamburg as an example.

## 6.2 Transition Management: Theoretical Framework and Practice-Oriented Process at the Same Time

Transition management is first and foremost “an approach that strives to influence the direction and pace of societal change dynamics” (Roorda et al., 2014, p. 54). Although the term ‘management’ suggests the element of control of the process, it refers in fact to a framework of concrete tools and methods that help to conceptualize and address the necessary and fundamental changes for sustainable urban development. Transition management thereby promotes an understanding of the complexity of the system and how it is to be influenced and changed, and operationally supports the formulation of common long-term goals in order to be able to implement short-term measures (Wittmayer & Loorbach, 2016).

In order to productively apply the transition management approach to the Fab City Hamburg, we focus on the central elements of the application of this approach. As a basis, we draw on relevant literature on the various approaches to transition research, most of which comes from the Netherlands and on which the remainder of this paper is based (Geels, 2002; Grin et al., 2010; Kemp et al., 2007; Loorbach, 2007, 2010).

### 6.2.1 Characteristics of Transformation Processes

There is broad agreement among experts on the key characteristics of transformations (Köhler et al., 2019; Heyen et al., 2018; Wittmayer & Hölscher, 2017). Transformation/Transition,[1] used synonymously, refer to process change, specifically from an existing, unsustainable, socio-technical system to a new, sustainable system. The transformation process from a linear economic system to an urban circular economy is one example. A system consists of a dense and complex set of relationships of social (incl. actors, norms, culture, policy, regulation) and technical components (incl. technical artifacts and infrastructures, technologies, applications) (Geels, 2002. Change toward sustainable development can only succeed through an interplay of these elements and thus involves technological, social, and cultural change (Geels & Schot, 2010). Therefore, it is also referred to as a “co-evolutionary” change (Rotmans & Loorbach, 2010; Wittmayer & Hölscher, 2017; WBGU, 2011, 2016).

Transitions are a complex, dynamic, non-linear process with uncertainties. It cannot be predicted ex ante which technologies and practices will prevail, what the change will look

[1] The terms ‘transformation’ and ‘transition’ have become new fashionable terms in the academic and sociopolitical debate (Brand, 2014), yet the distinction between the two concepts remains blurred (for an overview: Wittmayer & Hölscher, 2017). Transformation is often used to refer to comprehensive, whole-society processes of change, while transition refers to institutional political changes inside social systems (Wittmayer & Hölscher, 2017). Since the transitions between the terms often remain fluid, both terms are included below as subjects of transformation research.

like exactly, and where it will lead, though this will crystallize over time (Bauriedl et al., 2021). The complexity is primarily related to the diversity of actors involved in transition processes and the interactions they enter with each other (Frantzeskaki et al., 2009). Transitions cannot be "managed" from a top-down perspective. Instead, they require the coordinated involvement of many actors and groups of actors from politics, business, academia, and civil society (Heyen et al., 2018). Transitions are, therefore, multi-actor processes. Finally, transitions take quite some time, often lasting for decades, and are either rather incremental or triggered abruptly and radically.

Although the direction of change of societal transition processes is fundamentally open, and the processes cannot be specifically controlled or managed due to their high complexity and dynamic nature, they can nevertheless be intentionally influenced and accelerated (Heyen & Brohmann, 2017; WBGU, 2011, 2016). This is where the transition management approach comes in, which was introduced in research and politics in 2001 as a new governance approach for sustainable transformations (Rotmans et al., 2001; Grin et al., 2010). Transition management is applied as a participatory methodology that assists in challenging the status quo, developing a strategic perspective for the future, and establishing new practices in the local governance context that guide transformation and support it by bringing together and coordinating different actors and networks (Roorda et al., 2014).

### 6.2.2 Principles of Transition Governance

Based on these insights from analytical and operational transformation theory, a core set of governance principles can be summarized to provide orientation in transformation processes (drawing mainly on: Frantzeskaki et al., 2009; Roorda et al., 2014):

**Understand the Current State of the System** The system's complexity and dynamics must first be understood before strategies for change can be developed. This is done by analyzing the current situation and questioning existing assumptions, problem perceptions, and generally prevailing solutions.

**Aim for System Innovations in Small but Fundamental Steps** The goal is not a system optimization but system innovation that entails structural change that must be thought of in the long term (approx. 10–30 years). To minimize resistance from established regimes, focus on incremental changes that allow the system to test and build new structures.

**Leave Room for Diversity and Flexibility** Goals and strategies should be formulated in a flexible and adaptable way to better respond to change or resistance.

**Shape Actions Together** The aim is to include and involve diverse perspectives as a basis for formulating challenges and developing solutions, as well as for supporting policies.

**Create Space for "Pioneers of Change"** Actors who are already applying new and alternative ways of thinking should be brought in. They should be provided with the necessary resources and opportunities to realize their innovations.

**Promote Social and Institutional Learning Processes** Learning processes are crucial for social change. For this, sufficient time for reflection must be planned and an atmosphere of mutual trust and openness must be created. Social learning in transformation processes stimulates the development of visions, transformation pathways, and experiments.

### 6.2.3 Application of Transition Management in Urban Processes

These rather abstract governance principles have been translated into a transition management framework (i.e., the transition management cycle), which provides the basis for managing transitions in an operational sense. This framework distinguishes governance activities on four levels and links them to process tools for shaping transformative change (Wittmayer & Loorbach, 2016; Loorbach, 2010), see also Fig. 6.1. A transition management process is steered by a so-called transformation team, a core group whose main tasks are the definition of issue area and desired outcome, the creation of a process plan that is adapted to local conditions, and the driving of the overall process (Roorda et al., 2014). Since transition management processes are usually initiated from the municipal level, the core team is often composed of city government employees (though, in the case of Fab City, a different constellation of actors is emerging). There are four activity levels that characterize the transition management process.

**Strategic Level: Transition Arena (Instrument)** At the strategic level, the focus is on long-term activities involving the joint development of a vision and future goals. For this purpose, the so-called transition arena was developed as a process instrument. As a setting, the transition arena offers an informal, well-structured, temporary framework in which a small group of pioneers of change – about 10–15 participants – from different backgrounds (authorities, companies, research institutes, NGOs, citizens, intermediaries) come together to work on a vision. Ideally, the participating actors should be able to think beyond existing interests and standard procedures in their organizations and institutions. They form a network of frontrunners who are selected on the basis of their competencies, interests, and background (Loorbach, 2010, pp. 173–174). They do not participate in the transition arena as representatives of their institutions but as private individuals.

In the transition arena process, the actors must first come to a common understanding of the underlying problems and transformation challenges. This is the starting point for the subsequent vision development. The diversity of actors that come together here is key to bring different perceptions of problems and values that lead to new insights and perspec-

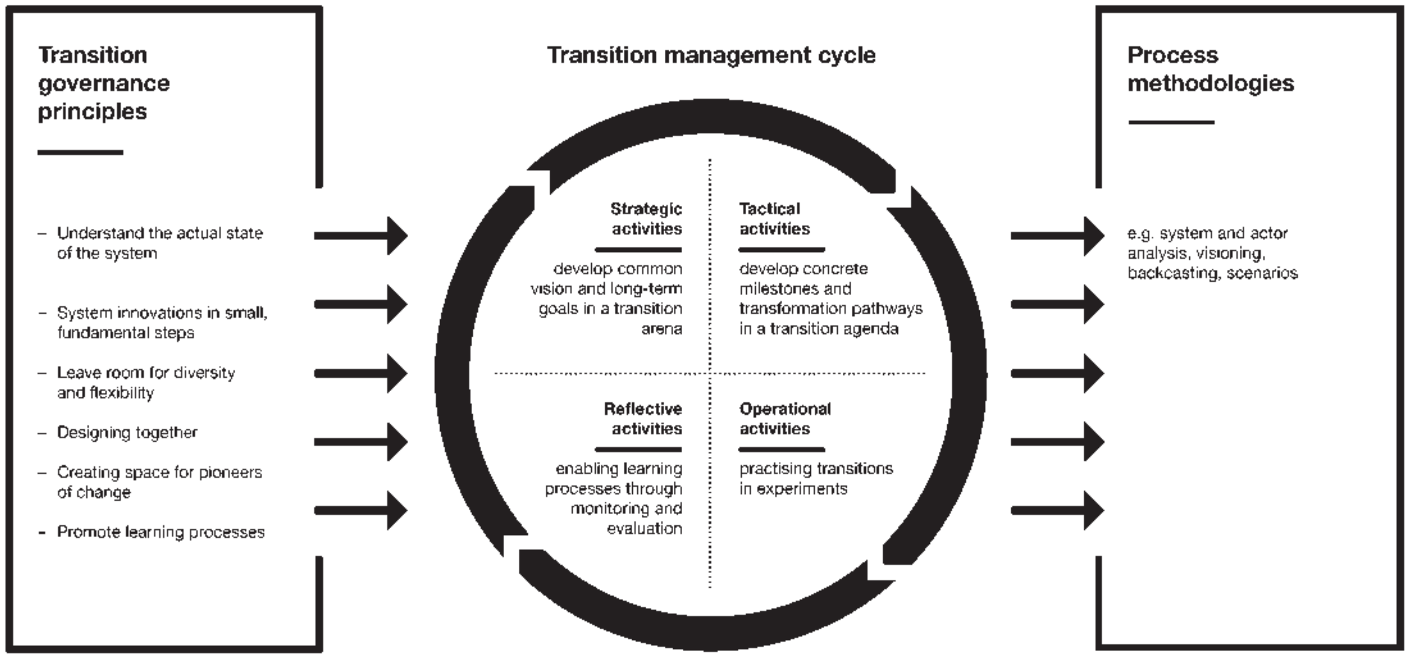


**Fig. 6.1** The transition management framework (authors' depiction, based on: Wittmayer & Loorbach, 2016)

tives. The transition management approach is essentially about questioning the stakeholders' assumptions and problem perceptions (Roorda et al., 2014).

Building on the common problem definition, the actors exchange their ideas on different perspectives for the future and develop a common vision based on shared basic principles for long-term sustainable development, while at the same time leaving room for dissent on short- and medium-term solutions, goals, and strategies. The vision is not intended to and cannot predict the future; rather, it points the way forward and creates framework conditions that determine the scope for future transition activities.

**Tactical Level: Transition Agenda (Instrument)** At the tactical level, the focus is on medium- to long-term activities aimed at changing established structures, institutions, regulations, and infrastructures. Concrete intermediate targets and transformation pathways must then be derived from the long-term goals, showing how to achieve this vision, i.e., the transition agenda. These should be translated into practical measures and regulations. Transformation pathways describe a possible set of steps from the present to the envisioned future. These are not concrete plans or detailed scenarios. They are inspiring action frameworks with short-, medium-, and long-term goals and action ideas identified, for example, using the backcasting method (Quist et al., 2011, 2013) or transition scenarios (Sondeijker, 2009).

The transition agenda serves as a starting point for the expansion of the group of involved actors and stimulates new activities, networks, and collaborations (Roorda et al., 2014). On this tactical level, recruitment should involve actors who have sufficient authority and room to maneuver within their own organization and who know what opportunities their organizations have to contribute to the desired transition process. An important prerequisite for this is that the actors involved are able to "translate" the transition vision and the resulting consequences into their own organization's agenda. As participating organizations and networks begin to adapt their own policies and actions in this way, tensions will emerge between the transition arena and day-to-day political agendas.

The focus at the tactical level is therefore also on the structural obstacles that stand in the way of desired development. Such obstacles can be path dependencies, lock-ins, fears of change, vested interests, as well as issues arising from the plurality and diversity of possible changes, the uncertainty attached to possible solutions, and different norms and values (Wittmayer & Hölscher, 2017). Should these structural obstacles be insurmountable, alignment at the strategic level needs to be reviewed, and a new transition arena may need to be built with some existing, as well as new, actors. At these points, the iterative process of transition management clearly emerges, and it becomes apparent why transitions are societal learning processes that are never fully completed.

**Operational Level: Transition Experiments (Instrument)** At the operational level, the focus is on short-term activities that concentrate on experiments and actions. A transition experiment is an innovation project that uses a societal challenge as a starting point for learning to contribute to a transition (Van den Bosch, 2010). Experiments are derived from the sustainability vision and overall goals and fit into the identified transition pathways. It is also possible to link them to innovation experiments that are already taking place – as long as they fit into the context of the transition.

In experiments, actors address the identified societal challenges in practice and therefore experience the real obstacles and drivers of change directly by “practicing” transition (Wittmayer & Loorbach, 2016). Experiments thus provide important insights into desired transformation pathways and the barriers to that transformation. Since transition experiments are costly and time-consuming, it is important that existing infrastructures (physical, financial, institutional) are used for experiments and that their implementation is continuously evaluated and assessed. If an experiment has been successful in assessing the learning experience and its contribution to transition, it can be replicated in other contexts (expansion) and extended from the micro to the meso level (up-scaling) (Loorbach, 2010).

**Reflective Level: Monitoring and Evaluation (Instrument)** The reflective level aims to evaluate and assess both the transition process and the transition management. The monitoring of the transition process refers, among other things, to changes in the system concerned, niche developments, and movements of actors at the regime level. Monitoring of the transition management includes the actions of the actors within the transition arena, the goals and instruments of the transition agenda, and the findings and insights from the transition experiments. Continuous monitoring is an essential part of the identification and learning process of transitions because changes in the urban fabric and dynamics can only be registered through reflection, the existing instruments be adapted, and new insights be formulated (Wittmayer & Loorbach, 2016). Transition monitoring aims not only at collecting data but also involves interventions based on these data (Taanman, 2014).

The framework’s cyclical nature suggests that activities at the strategic level are followed by tactical and operational activities and the cycle is closed with activities at the reflexive level. However, the cycle should be understood as being iterative (Loorbach, 2010). Activities can start at any level of governance and run parallel. For example, they can begin with experiments, and the learning from these experiments can affect the tactical level by highlighting the need for change in instruments or organizational structures and/or at the strategic level by illuminating needed adjustments of overarching goals.

In recent years, the transition management framework and tools have been adapted for urban contexts with process methodologies that can be used either within applied research (Wittmayer et al., 2014; Frantzeskaki et al., 2012) or by local authorities (Roorda et al., 2014) to implement this approach in cities. As an example, we refer to Roorda et al., (2014), who operationalized transition management in a process methodology for municipal decision-makers committed to climate change mitigation in their cities. However, transition processes are context-specific. The process phases, methodology, and tools need to be transferred and adapted to the specific challenges and issues in the local context (Wittmayer & Loorbach, 2016). The transition management approach does not offer a silver bullet for implementing ambitious sustainability goals (Nevens & Roorda, 2014) and is not a substitute for other policy interventions (Roorda et al., 2014). Nevertheless, the approach provides an impetus for change by helping to understand complex systems and develop a strategic perspective of the future. It empowers stakeholders to embrace challenges and opportunities for sustainable urban design and to practice new collaborative governance. Finally, the approach provides space for alternative ideas, actions, and social relationships that have the potential to change existing structures, cultures, and practices or transform existing policies over time (Wittmayer et al., 2014).

So far, transition management has been primarily concerned with the pre-development phase of transitions, focusing on strengthening frontrunners and niches (i.e., the process of transition arenas), while the acceleration phase of transitions may require a different focus and a deeper understanding of the institutional and policy context (Wittmayer & Loorbach, 2016). In general, there is no consensus on the importance of frontrunner actors and their selective participation. These are referred to as an "elite group" (Smith & Stirling, 2010), while, at the same time, a legitimacy deficit is seen due to selectivity (Hendriks, 2009). However, transition management is not a decision-making process: "transition management creates a framework for mutual inspiration between social actors in which new ideas, connections, and actions can emerge" (Roorda et al., 2014, p. 26).

## 6.3 Transition Management Approach and Fab City: Challenges and Opportunities Using Hamburg as a Case Study

In terms of structure and implementation, Hamburg is a 'mature' Fab City by international standards. This assessment is based on the evaluation by the Fab City Foundation and the authors' own empirical studies/interviews, including during the Fab City Summit 2022. In addition to a bottom-up ecosystem of labs and makers that has been active for a long time, EU and national-level funding support have allowed two large research projects and numerous initiatives to be launched in Hamburg and to be embedded in an overarching scientific monitoring and assessment effort. The landscape of actors is diverse and extends far beyond the research projects. Within the Fab City Hamburg, a university is a central steering and networking actor due to its role as lead partner of the research projects and as chair of the board in the association Fab City Hamburg e. V., which was founded in 2020. Fab City Hamburg e. V. is an association of Hamburg fab labs, makerspaces, workshops, innovative start-ups, and research institutions. The authors' access to this first-hand experience with Hamburg's transition has been used in the development of this article.

The Fab City Global Initiative predefines a diverse set of actors for a local Fab City founding coalition, incl. civic society, local government, and a fab lab. Negotiations among these actors requires a high degree of coordination and cooperation and appropriate governance. The transition management approach can help classify and interpret the ongoing processes in a Fab City and shows necessary actions.

**Governance of the Fab City Hamburg Strategic Activity Level**

While the global Fab City vision is the initiating idea and common framework for all Fab Cities, it must be adapted to local conditions. To this end, a system analysis must first build a common understanding among the actors about the problems to which the local Fab City concept is to provide an answer. Based on this, a jointly supported vision and initial transformation paths (transition agenda) are developed with selected actors in a transition arena, which act as a compass and provide orientation in the implementation of the Fab City. If this vision is communicated in emotionally engaging narratives, it has the potential to motivate the general public (Jacob et al., 2018).

Within the Fab City Initiative, various visioning processes have already been initiated and a Fab City Vision and transformation pathways have been worked on in workshops. However, these processes have involved only a limited group of local actors. In one workshop, it was the scientists from the research project who developed a common basic understanding; in the other workshop, the board of the association (Fab City Hamburg e. V.). These processes have proven to be important for the agreement on a common understanding and motivation, and they serve as orientation for the work within the different organizations. However, they are no substitute for the development of a shared vision for the future that is supported by a broader group of actors, including first and foremost the municipal level.

In Hamburg, shared visioning was attempted in a transdisciplinary ‘green paper workshop’, to which representatives from the local business community, government agencies and ministries, research institutions, and interest groups were invited. The aim was to develop a common understanding of the local challenges for transformation and a vision for the future Fab City Hamburg. As a result of the workshop, initial premises and assumptions were formulated in a green paper, which constitutes a prologue to further dialog with an expanded circle of stakeholders. The workshop therefore characterizes the starting point for a broader transition management process.

However, the activities have so far not been carried out in a sufficiently systematic way. The first step in a transition management process is the formation of a transformation team that manages the overall process. The second step is a system and actor analysis. Only from this can the circle of relevant participants for the transition arena be derived.

**Tactical Activity Level** At the tactical level, the collaboration to date has mainly addressed contextual questions from researchers about how local, national, or transnational governance structures would need to change to support the development and implementation of Fab City Hamburg. Initial learning experiences from the operational activities – the projects, existing Fab Labs, and initiatives – have already shown where the obstacles and drivers for transformation lie and which structures, instruments, infrastructures, rules, and regulations need to change. The restrictions that have emerged include investment support, funding programs and innovation policy, regulations on land use as well as the provision of (municipal) land and premises, and, finally, the creation of exceptions, i.e., experimentation clauses for the testing of new products. This is only a sample of the hurdles already identified.

In addition, there is the question of how the Fab City can be embedded in city and regional governance structures and dynamics. Relevant topics include municipal concepts, strategies, and visions (e.g., climate plans, integrated urban development concepts, inner city concepts or circular economy strategies, educational landscapes), which should strategically and conceptually consider Fab City ambitions. Further topics and activities from the federal, state and EU levels may also be relevant for the local context and the promotion of the Fab City (e.g., European Green New Deal, green public procurement, Right to Repair or the German government's circular economy strategy currently in progress), which calls for a discussion on how these can be addressed and implemented locally. Not all challenges can be addressed and solved at the local level. It has become clear, however, that tactical activities require actors from politics, administration, and business who have sufficient authority and have room to maneuver within their institution or organization and know how to implement change.

**Operating Activity Level** In Fab City Hamburg, there are a number of initiatives and projects that can be understood as transformation experiments. These include:

- the existing and new open production labs (Fab Labs, Open Labs and Makerspaces). Open Labs have a special status as funded research projects, enabling them to test prototype manufacturing solutions for various trades in a protected space, detached from the usual development and selection mechanisms of the market (Open Lab Circular Textiles, Open Lab Circular Plastics, Open Lab Port, Open Lab Mobile, Open Lab MedTech, Open Lab Agri-Food),
- the Open Lab Starter Kit, which enables self-replicating machines to be built in the Labs,
- the Fab City OS operating system, which aims to bring together global product development with local manufacturing,
- the city-wide Maker Challenges to generate product and design ideas,
- the development of educational formats and the participation of citizens in the context of build workshops, and
- the development of a Fab City Index to capture local production capacities as well as consumption and material flows.

In these sub-projects, fundamentally different ways of meeting societal needs are explored and practiced. These projects already capture local structures and dynamics in parts (e.g., mapping of small production sites), and, thus, contribute to systems analysis, which is the basis of any transformation process. A variety of lessons continue to be learned from the experiments: from institutional aspects, to safety and liability issues to cultural aspects, such as the motivation to design, make, or repair things oneself. These learning experiences must in turn flow into the other levels and contribute to change there. So far, however, there are no platforms and instruments for a coordinated exchange and learning from the experiences of the experiments in the Fab City Hamburg. Introducing a fixed regular time for meetings lika a round table could be suitable format.

**Reflexive Activity Level** Initial evaluation and monitoring activities have already been established within the framework of Fab City Hamburg: at the level of the individual projects – in the context of the accompanying research on the Open Labs and the build workshops or also in the context of the contributions in this publication – and at the superordinate level of the two research projects. So far, the individual projects are only related to each other to a limited extent. While there are a number of formats for exchange and networking at the superordinate Fab City level, e.g., round tables, working groups, and Fab City Summit, there is too little of this at the local level inside of Hamburg. In order to generate systematic learning processes, there is a need for "horizontal" exchange formats between the various Fab City projects, experiments and initiatives, in which knowledge and experiences are shared in order to draw conclusions for the "vertical" level.

**How Can Transition Management Support the Development Towards a Fab City Hamburg?**
We have classified the numerous activities in Fab City Hamburg in a transition management approach. From this exercise, it is clear that a structuring framework that brings together the multiple actors and activities in a coordinated process is not yet in place here. In particular, the municipal level has so far only been involved in rudimentary ways – such as the Green Paper Workshop. Politics and the administration are relevant groups of actors in transformation processes because they set socially binding rules at different levels (from local to international) and can thus also improve the framework conditions for other actors (Heyen et al., 2018).

The first step in the transition management process of a Fab City would be the formation of a transformation team to coordinate and steer this overall process. Usually, such a process is initiated by municipal decision-makers, with the city administration also providing the core team. Considering the constellation of actors in Fab Cities, however, this process can and should be steered by a broader group of actors. Representatives from all institutions and organizations that belong to the respective Fab City consortium could be included. As with Fab City Hamburg, this role could be assumed by the Fab City Hamburg e. V. (association), which acts as an interlocutor and takes a mediating role between the various actors and initiatives from the field. The Fab City e. V. is also intended to coordinate the Fab City Hamburg initiative, independent of the funding projects.

The second step in the Fab City transition management process consists of a system and actor analysis to better understand the urban dynamics and enable a co-creation process. With the help of the system analysis, an integrated overview and a better understanding of the selected topics is gained: How do different elements influence each other? How has the status quo evolved? The systems analysis creates a common information base for all stakeholders and a shared understanding of the city (Roorda et al., 2014).

Within the framework of the many projects and initiatives in the Fab City Hamburg, various data have already been collected that are relevant for the system analysis. It helps to define the relevant thematic field-specific actors, who in turn can be considered for the selection of arena participants or for participation in later phases of the transition management. There are a variety of procedures and techniques for conducting the actor analysis, of which a systematic one has still not been done in the context of Fab City Hamburg.

## 6.4 Conclusion and Outlook

The Fab City approach is one possible way to collaboratively address sustainability challenges in urban spaces. In this article, we explored the question of how the transition management approach can contribute to shaping the transformation to a Fab City, using Hamburg as a case study. To this end, we first outlined the basic characteristics of transformations in order to describe the complexity of the task. Transformations are defined as radical, structural change of a social system toward sustainability as a result of co-evolution of technological, economic, socio-cultural and institutional changes and involving a wide range of actors (Rotmans & Loorbach, 2010; Geels & Schot, 2010). They are complex, dynamic, nonlinear, and usually span several decades. Although transformations cannot be planned or controlled, it has been suggested that they can be influenced in direction and speed (Heyen & Brohmann, 2017; WBGU, 2011, 2016). To this end, various governance approaches have been developed that aim to understand, analyze, and shape transformation processes toward sustainability (for an overview: Köhler et al., 2019). In the article, we focused on the transition management approach in its operational application to a Fab City. Based on a set of transition governance principles that act as orientation and clarify what to look for in transformation processes, the transition management approach was operationalized in the form of iterative governance activities at four levels. Regardless of the specific process design, which must be tailored to the local context, transformation processes should include strategic, tactical, operational, and reflective activities.

Finally, the transition management framework was applied to the case study of Hamburg and used to analyze where the Fab City Hamburg stands in terms of governance activities. The application of the framework for a real-world urban experiment is intended to illustrate the perspective of the transition governance approach. From this perspective, despite numerous activities, comprehensive governance of the transformation to a Fab City Hamburg has not yet taken place. The strength of the transition management approach is to practice a new collaborative governance with the help of the tools (especially the transition arena) and methods (including visioning, backcasting, etc.) by coordinating diverse actors and networks, and building new competencies. The founding constellation of Fab City consortia already provides an important basis for this, on which coalitions can be built. In Hamburg, civil society actors, startups, and research institutions have founded an association to address the transformation goal of the Fab City – to transform the "city" system into a digitally and globally networked Circular City – in a coordinated manner. The creation of such a collective, association, or similar formal organization helps the local Fab City movement to become active, to be visible, and to appear coherently to the public. Nevertheless, the authors recommend an expansion of the group of actors to include more frontrunners and other groups of actors, especially from the field of politics and administration. This would support the achievement of broader impact in Hamburg and bring about changes, especially at the tactical level, with regard to established structures, institutions, regulations, and other instruments.

A key challenge of transition management is to engage in a long-term, open-ended process that complements political and civil society action. This requires human, financial, and time resources. From the perspective of transition governance, fab cities will only develop their intended transformative effect if, beyond the niche activities of pioneers of the fab movement and research elites, actors from politics and administration as well as from business can also be activated. A moderated transition process using the methods presented in this article could contribute to this and go beyond internal organizational and/or selective exchange.

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# 7 Decentralized Autonomous Organizations (DAOs) as Innovative Means to Supplement Transition Governance

## A Pragmatic Approach to Conceptualization and Implementation in Fab Cities

Alex M. Pawlowski

## 7.1 Introduction

### 7.1.1 Governance Acceleration

Large-scale transformations set in motion in response to pressing and complex challenges (in this case, with a transformation of urban environments such as Fab Cities to circular economies) not only require a thorough understanding of situational analysis and target setting but an exhaustive overview of variables involved in the capturing of the various rule sets, actor constellations and specific conditions that have to be dealt with. Considering such a process which is not only lengthy but difficult to administer creates the need for transparency and dynamic adjustment of the status quo.

Governance is the key to the provision of an approach to systematic transitions as it rests on effective coordination with accountability, predictability, and common understanding (Okhuysen & Bechky, 2009). Traditional analog approaches to guide such processes are prone to issues like information asymmetry, missing transparency, lack of consensus in decision-making, and corruption among other things (Kim, 2021).

While technology alone holds no ultimate answer to real-world challenges, recent decades have brought massive advancements in computational, storage and bandwidth capacity to deploy and scale solutions, in this case with decentralized technology. Block-

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chain, the decentralized state machine and economic middleware[1] (see Fig. 7.1) for the internet of ownership, serves as a governance tool that facilitates coordination and builds on simultaneous transparency and privacy. The technology acts as a de facto ERP system[2] for the internet as it provides a general settlement layer on the TCP/IP[3] protocol to prevent any single point of failure and offers both transparency and privacy in the process (Haddara et al., 2021). The novel aspect that comes to attention is decentralization.

Blockchain technology is a digital system that records ownership and transactions without relying on a central authority. This is achieved through the use of digital signatures and validation from independent nodes. Each ledger entry is controlled by its respective owner, and updates to the ledger are decentralized through a consensus mechanism such as Proof of Work or Proof of Stake. This ensures that any changes to the ledger are agreed

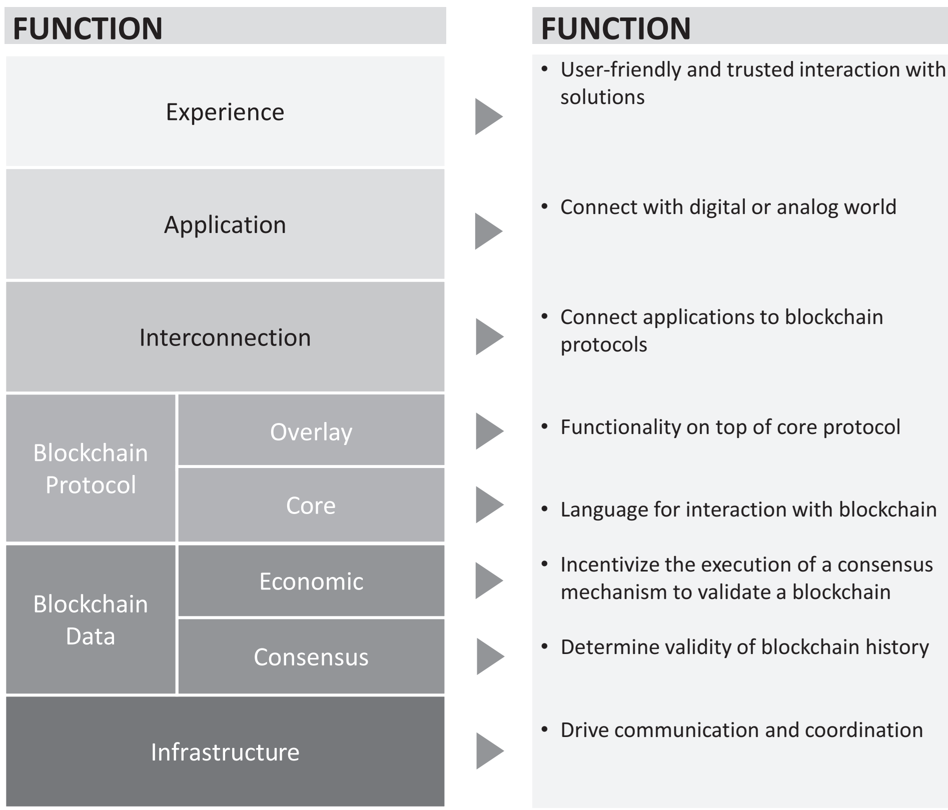


**Fig. 7.1** Schematic blockchain-based system

[1] A type of computer software that provides services to software applications beyond those available with the operating system.

[2] Enterprise Resource Planning, a system that manages activities and processes for an optimal performance.

[3] A framework for organizing the set of communication protocols used on the internet.

upon by all nodes holding the ledger. The ledger is tamper-proof and provides a complete and accurate history of all transactions, allowing for an auditable trail of events (Davidson et al., 2016).

A technical solution to large-scale transformations that captures activities and offers provenance over events in near real-time may find an answer in blockchain technology and additionally the creation of dApps.[4] The result may provide governance acceleration as co-ordination with accountability, predictability, and a common understanding for more manageable parameters.

The following article describes a pragmatic approach to DAO implementation in urban environments, in this case Fac Cities. First, I will lay out the theoretical background on the subject matter before describing the solution alternative and providing a discussion around its relevance.

## 7.2 Theoretical Background

### 7.2.1 DAOs (Decentralized Autonomous Organizations)

DAOs have only emerged in recent years but have come under increased attention as a niche application of blockchain technology and the interplay between machine consensus, social consensus, and decentralization mechanisms. In the simplest terms, a DAO defines an entity with a group of interest at its core that uses the blockchain and related technologies to coordinate common activities (Faqir-Rhazoui et al., 2021).

Coined in the 1990s by German computer scientist Werner Dilger (1997), a DAO offers a new form of organizational control and potential solution to the four universal problems – task division, task allocation, reward distribution, and information flows (Puranam et al., 2014). Traditional corporate governance involves management and formal legal structures to operate a company. However, DAOs (decentralized autonomous organizations) aim to operate in a decentralized manner. They run on public, so-called permissionless blockchains and follow behavioral rules that are encoded in open-source software protocols. These rules are enforced by smart contracts,[5] which eliminate the need for intermediaries and create a transparent and efficient system (Tse, 2020).

DAOs operate differently from traditional businesses or entities by distributing control among their supporters or members instead of allocating it to a single individual or group. This approach eliminates the traditional principal-agent relationship and replaces third-party supervision with automated rules and machine algorithms, leading to a transformation in the overall perception of governance (DuPont, 2017).

An otherwise analog governance process can benefit from this novel set of coordination mechanisms based on machine consensus, which interact with coordination mechanisms

[4] Decentralized applications.

[5] Simple programs stored on a blockchain that execute when predetermined conditions are met.

around social consensus and decentralized decision-making on improvement proposals.[6] The concept works on three levels (see Fig. 7.2):

I. Decentralization of decision-making with the institution

***Example:*** *developers and network validators in a non-profit institution decide collectively on the strategic direction of digital and physical infrastructure. Loosely coupled, the organization uses the DAO to decide collectively on the strategic direction while aligning all parties' interests in the process.*

II. Human consensus in the peer-to-peer network

***Example:*** *updates to the ecosystem (digital and physical infrastructure) are approved by the community and need to be activated by validators who vote and commit resources (e.g., computing power).*

III. Machine consensus among network validators

***Example:*** *network validators write machine routines into the blockchain's open-source code.*

In addition, the DAO process uses governance tokens to both showcase the membership to the community and the qualification to submission of improvement proposals and decision-making (stimulation by participation). Greater transparency, trust, adaptability,

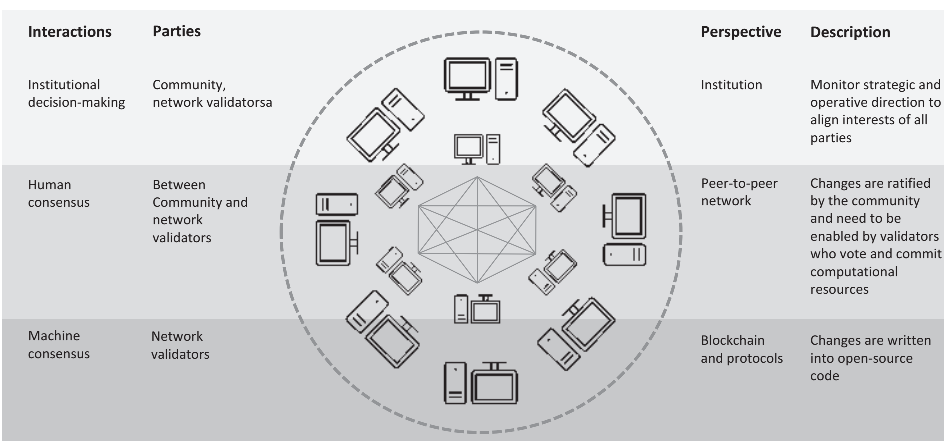


**Fig. 7.2** Coordination with DAOs

[6] Improvement proposals are written submissions by DAO members for a collective decision-making specifying an outcome.

and speed enable rapid experimentation and the potential to direct activities towards a multiplicity of goals (Tse, 2020). At the same time, the elimination of agency costs without a particular board of directors may drive efficiency through automation and boost accountability, predictability, and common understanding in the collaborative effort (Hsieh, 2018).

## 7.3 Solution Alternative

### 7.3.1 Potential

Due to the high complexity in rule sets, actor constellations and conditions of the host environment, a transition to a circular economy requires a high degree of coordination when implemented, aiding the transitioning phase of user onboarding and ongoing efforts to uphold onboarding and continuous engagement. Supplementing such an undertaking with coordination technology, thus, provides the ideal precedent for a DAO to facilitate and accelerate a governance approach that is based on collaborative visioning, learning, and experimentation (Bocken & Antikainen, 2018). The design of a decentralized governance system with a DAO implementation might be characterized as showcased in Table 7.1.

Development of the DAO on transparent and open-source infrastructure, participation from developers, projects, and subject matter experts are welcomed, to both shift to this new economy and be rewarded for their contributions.

**Table 7.1** Overview of DAO characterizations

| | |
|---|---|
| Purpose | Decision-making around strategy and execution affect digital and physical infrastructure among other things |
| Users | Active community members, small–medium sized enterprises, government authorities, grants makers, and affiliated stakeholders (among others) around the project ecosystem get the opportunity to participate in the decentralized ecosystem via governance tokens |
| Medium of exchange | Governance tokens are fungible:[a] per the ERC20 token standard |
| Use | Holders of the token gain the ability to vote on ecosystem-specific DAO policy |
| Treasury | Serves the role of fund administration, governs the monetary policy, and provides liquidity for individual urban environments and projects within those urban environments; over time, a dedicated economy is built by driving adoption and unlocking community growth |
| Fair participation | Governance tokens can be swapped according to the platform economic model but are also allocated depending on the group of stakeholders; after a set period, the token score is reset to enable new entrants in the community to have more equal opportunities; it is not available for external speculation |

[a]The ability of goods or assets to be interchanged with other individual goods or assets of the same type

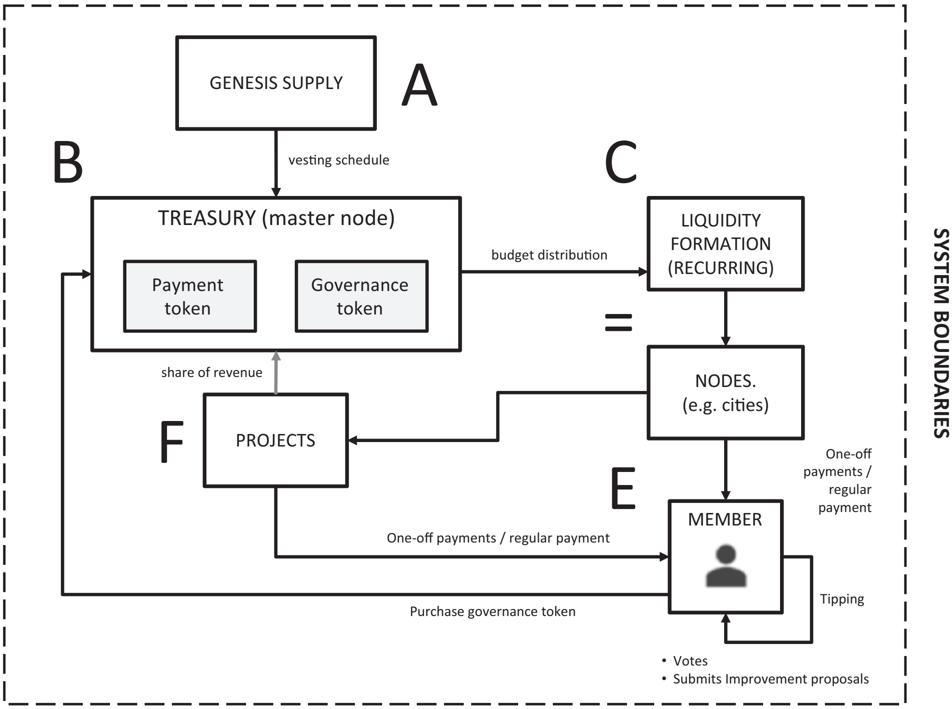


**Fig. 7.3** Simple DAO concept

From a systematic perspective (see Fig. 7.3), a simple DAO embedded in an urban environment may consist of a treasury, network validators (nodes), and projects including members acting on those projects. Table 7.2 illustrates the associated process.

### 7.3.2 Requirements for Set-Up and Management

Setting up and running a DAO will involve several requirements when conceptualizing the operation of this novel organizational model. The first critical step in DAO formation is gathering like-minded individuals around a common purpose. In many cases, DAOs will find their first momentum in social media platforms or result from real-world organizations. The foundational members work together to determine the DAO's purpose, agree on parameters for governance and develop a rollout plan. DAO communities are also built around an existing community or blockchain-based application.

The set-up will usually begin with the manifestation of a community goal or purpose, for instance, a concrete and measurable or abstract goal like a collective investment or outcome. This phase will likely be established in founding documents, either articulated in-

**Table 7.2** Elements in simple DAO concept

| | |
|---|---|
| A | The initial genesis supply (first emission) in tokens is emitted and poured into the treasury (e.g., via vesting schedule) |
| B | The treasury acts as a master node (e.g., a global foundation) and does two things: safeguard the overall mission of the DAO and administer the total amount in funds (monetary policy) |
| C | To provide nodes (e.g., cities) with liquidity, a recurring outflow from the treasury is initiated |
| D | Nodes are both responsible for network validation and further token distribution to projects and member participants |
| E | Member participants either earn (swap) or purchase governance tokens to showcase their membership to the community and are thus eligible in decision-making; they submit improvement proposals for the collective decision-making and vote themselves |
| F | Projects are all initiatives that generate value from member participants' activities to finance the basic cost for running the system and compensating member participants |

**Table 7.3** Basic requirements in DAO formation

| | |
|---|---|
| Constitution | A statement of purpose, including mission, vision, values, and objectives |
| Proposal | The decision-making process will start with a proposal that is put forward by a member. Proposals can range from cybersecurity upgrades to overhauls of the organization's purpose |
| Token | Valuable property is contained in the form of tokens,[a] representing the voting power and being used to reward each member |
| Autonomy | Independence without external influence are core attributes. Both open-source code and the organization are fully transparent. Core functionalities and rule sets are hard-coded on the blockchain and history of changes immutably notarized and opened to third parties' audit |
| Consensus | In the event of decision-making, for example, to make changes to the infrastructure, members need to agree democratically |
| Contractors/ core contributors | The DAO "hires" specialists, developers, and other contractors based on community decisions to accomplish tasks and reach business goals. In the case of Fab City, core contributors can be designers, manufacturers but also (local) government members, owners of FabLabs, universities and other value chain participants that can and should affect the core DAO purpose |
| Voting | Strategy and execution are determined by activities like raising funds, collective investments and improving infrastructure among other things to take place if a majority vote is reached. |

[a]Tokens themselves do not create value, instead they capture and transfer it

formally or captured explicitly in a "constitution". With an initial purpose defined, a DAO will, over time, morph into a movement, a grants organization or much more (WEF, 2022). Table 7.3 lists the most basic requirements.

After the group has reached a consensus, they can translate their mandate and regulations into smart contracts, which will hold the group accountable for their decisions. Some DAOs prefer to write their own rules, but DAO creation platforms offer pre-made resources to generate smart contract code. Individuals who use DAO creation services can customize various parameters like the main token, proposal frequency, voting duration, as well as voting and proposal mechanisms (WEF, 2022).

DAOs typically use a digital asset to represent membership, which is called a "governance token". Holders of these tokens can suggest and vote on modifications to the protocol. The voting mechanism in DAOs provides an alternative to traditional hierarchical and managerial decision-making processes used by conventional companies. In a DAO, different stakeholders could hold varying amounts of governance tokens that give them the right to vote based on the number of tokens they possess (Kondova & Barba, 2019).

As of July 2021, Wyoming became the first state in the US to establish regulations explicitly for DAOs to be based in that state. The updated rules designate DAOs in Wyoming as a unique kind of limited liability company (LLC), providing them with legal status and offering numerous rights, including limited liability for its members. If a DAO does not have this legal protection, it may be seen as a general partnership, and its members could face personal liability for the DAO's commitments or activities. To comply with these new laws, every DAO must appoint a registered agent located in Wyoming. This agent must establish a physical address and maintain a register of names and addresses of the entity's directors or individuals serving in a similar capacity (*Wyoming Secretary of State – Business Division 2022*).

### 7.3.3 Challenges

Before DAOs can establish themselves as functioning entities, there are several legal/regulatory, social/systemic, and technical challenges ahead. These are summarized in Table 7.4.

**Table 7.4** Overview of DAO challenges (Tse, 2020)

| | |
|---|---|
| Legal and regulatory | |
| Jurisdictional uncertainty | No registry with a fixed location as it operates in a decentralized manner. This raises questions about tax implications |
| Legal status | Associated with the location is the question about the legal form of society the DAO would represent. This will determine the laws and legal protections the members and shareholders of the DAO would need to adhere to (Kypriotaki et al., 2015) |
| Social and systemic | |
| Voter incentivization and engagement (fatigue) | Active and persistent engagement is challenging to uphold. Specific voter participation thresholds may pose a viable solution besides incentivization |
| Information asymmetries between creators and contributors | Missing detailed information leads to power concentration |
| Power concentrations on the vision of decentralization | Creators are often too closely affiliated to DAO after launch |
| Technical | |
| Security | Protocol-specific weaknesses |
| Decentralization/scalability | Protocol-specific weaknesses |

## 7.4 Discussion

DAOs are fascinating innovations that bring great potential to purpose-driven organizations and movements. These novel entities attempt to bring a higher degree of transparency into functional and financial information flows by empowering members to participate in decision-making. Making decisions, directing resources, and coordinating activities has led an ever-increasing number of organizations (approx. 11,500 DAOs, according to the tracking tool deepdao.io/organizations, March 2023) to use either blockchains, digital assets or related technologies. With the private sector from various industries, functions and use cases leading the uptrend in DAO innovation, it is imperative for both regulators and policymakers to make sense and develop a reflected viewpoint of both the technology and its implications.

DAO advocates persist that this novel innovation can offer a path to democratize management and a wide variety of aims, including prosocial objectives and generally address the limits of centralized governance. With advantages around increased transparency, adaptability, and speed efficiencies, blockchain technology, open-source software, and smart contracts are here to stay.

While promising in potential, DAOs have yet to resolve several impending challenges around privacy and regulatory uncertainty, cybersecurity, engagement, and scalability that hinder a greater expansion in both business and society. Advocates are optimistic about the prospect of a total global shift from centralized to decentralized organizations. As ironic and simple as this proposition might appear, the technology quickly expands its potential (Tse, 2020). However, for the DAO to become a business structure that is both viable and competitive, it will have to be integrated into the existing legal system. Likewise, relationships between incumbents and DAOs need to be closely monitored, be it by governments or competing organizations.

Maintaining the decentralized structure will pose yet another challenge as it requires a comprehensive approach to structuring the DAO in a manner that resists the natural tendency of centralization. On the other hand, power concentration needs to shift away from the creators who are responsible for the design and set-up (Tse, 2020).

Assuming we remain on a steady path to improved technology from an engineering perspective and considering all other challenges mentioned, a hybrid future of centralized, partly decentralized, and fully decentralized organizations may seem most likely from today’s perspective (Tse, 2020). With great innovations underway, deployment of DAOs is following its increasing global interest and adoption, from functions as varied as grantmaking, social networking, or social impact.

The potential for Fab City itself lies in the proposal of changes to both physical and digital infrastructure, the election of core contributors and personnel but also fundraising and allocation of funds. It may even expand to legislation and drafting of legal bills or frameworks that undermine the path towards a circular economy.

## 7.5 Conclusion and Outlook

The potential of DAOs as governance tools powered by blockchain technology is enormous. They can be used to address large-scale transitions that involve various variables and complexities in coordination and collaboration.

Fab City has a vision of transforming the urban landscape worldwide into a sustainable model of self-governing entities that reduce physical flows of goods and prioritize the exchange of data and information. In this context, DAOs offer an interesting solution to the scalability of Fab Cities and the general shift towards circular economies. They can assist in aligning associated entities in a federated network, which is essential for managing the complexity of these transitions.

In the coming years, we can expect to witness a blended method for incorporating DAOs into society. This approach will involve multiple aspects. Firstly, DAOs and traditional corporations will coexist and collaborate with each other. Secondly, there will be combined regulatory approaches to address associated challenges. Lastly, there will be differing levels of centralization within DAOs, with some resembling traditional corporations and others being fully self-governing (Tse, 2020).

This article anticipates a gradual adoption of DAOs into society, taking into consideration the challenges that come with technological advancements. To overcome these obstacles, a hybrid approach that combines temporary legal solutions and varying levels of automation and decentralization is likely to be used (Tse, 2020). The combination of DAOs and artificial intelligence (AI) can potentially address at least some of the challenges faced by DAOs. As AI technology advances and becomes more accessible (e.g., ChatGPT), there may be several use cases where it can benefit DAO development.

In the short- to mid-term, AI bots and assistants are expected to enhance productivity and improve the quality of products/services offered by DAOs. Over time, AI is likely to become more integrated with the core smart contract of the DAO and may even act as a token holder (Aragon's Blog, n.d.). In the long-term, we may even see AI connectors within or between DAOs, which may form a "swarm intelligence" or a DAO that governs AI as a public good to ensure AI safety (Aragon's Blog, n.d.). In any way, the future is likely to witness more progress in exploring the interconnection between social material practices, human-machine agency, and institutional change with decentralized, automated, and autonomous principles.

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# Implementing a Digital Product Passport to Support the Open-Source Hardware Community

8

Denis Roio, Adam Burns and Stefano Bocconi

## 8.1 Open Source Hardware

The open-source hardware (OSH) movement is a critical enabler of a more sustainable and decentralized economy. At its core, the OSH movement is about making hardware designs and specifications freely available to anyone who wants to use, modify, or distribute them (OSHA, n.d.-b).

Cooperation and knowledge sharing are among the OSH movement's underpinning concepts, shared with the broader free and open-source software movement. By sharing hardware designs and specifications openly, OSH communities seek to leverage its members' collective knowledge and expertise to create better, more efficient, and sustainable hardware products (OSHA, n.d.-a).

Local production is also essential among the OSH movement's underpinning concepts. By openly sharing designs, specifications and manuals at different scales (city, regional, national or global), communities can produce their hardware locally, using local resources and skills. Local production of OSH designs has the potential to reduce transportation and logistics costs, lower the carbon footprint of production, and support the development of more sustainable local economies (Kostakis et al., 2015).

The OSH movement is also closely linked to the circular economy transformation in Europe and related to important initiatives such as the "Right to Repair" (Right to Repair, n.d.; Svensson et al., 2018; Hernandez et al., 2020). Such initiatives are shaping Europe's future policies about the consumer market of hardware products. By enabling local production and the reuse of components and materials, OSH supports the development of

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more circular value chains, where waste is minimized, and products and materials are kept in use for as long as possible.

The backbone of the OSH movement is a growing ecosystem of maker spaces, fab labs and hackerspaces, as well a growing academic corpus that prompted the creation of a *Journal of Open Hardware* (Murillo & Wenzel, 2017). Such a vibrant and expanding movement has created a vast amount of projects available globally and build locally: they often share common components or are derivatives including modifications and combine diverse parts developed within the global OSH ecosystem. In order to account for authorship and liabilities as well as to trace the life-time and quality of both materials and machinery involved in their production, a very complex network of information is necessary. Our effort is to implement such an information system ad hoc on the needs of OSH and produce a "Digital Product Passport" format that can be printed along the products and linked to its "digital twin" in the global database of OSH creations.

The source of this article's findings is the continued participatory research activity deeply ingrained into this ecosystem, for instance, in the context and success of the European REFLOW project (European Commission, 2022) or the more recent INTERFACER project (Interfacer, n.d.-a). These community-driven innovation spaces provide access to tools, resources, and expertise for hardware prototyping and production. This ecosystem is driving the democratization of hardware innovation, empowering individuals and communities to create their hardware solutions and participate in the circular economy transformation.

### 8.1.1 Digital Product Passport

The digital product passport (DPP) is a crucial enabler of the transition to a circular economy. Providing valuable information about a product's design, material composition, and environmental impact supports the development of more sustainable business models and value chains while also reducing waste and increasing the efficiency of logistics and accounting functions when recycling materials and components.

A DPP as represented by a machine-readable data carrier (such as a QR code), contains a unique product identifier as well as linked data references not only to attributes such as its design and constituent materials but also process details spanning across the product's life cycle – from manufacturing and usage to disposal and recycling (European Commission, 2022d).

The wide adoption of a DPP standard has the potential to facilitate fine-grained transitions to a circular economy, from the local to the global. A circular economy aims to keep materials in use for as long as possible, minimizing the entropy created by production processes: an externality known as waste and pollution. Products must be designed with their end-of-life in mind, and materials must be recovered, reused, or recycled to minimize the entropy of production processes.

DPPs can provide valuable information to enable this transition by facilitating the tracking of materials and products throughout their life cycle. Initiatives willing to produce open hardware can use this information to optimize recycling processes, reduce waste, and support the development of new business models and value chains.

For example, by providing information about the materials and components used in a product, a DPP can facilitate identifying and separating these materials for recycling. It can also provide information about the materials' quality, lifetime, and condition, thereby enabling more effective recycling processes.

#### 8.1.1.1 What a DPP Should Provide

At the heart of the European Commission's European Green Deal strategy (European Commission, 2019), the Ecodesign for Sustainable Products Regulation (ESPR) (European Commission, 2022a) defines DPPs as the technical cornerstone for achieving its aims. DPPs are designed for all participants along a value chain, from designers, manufacturers, distributors and end users to repairers, re-manufacturers and recyclers, to cooperatively access information that is valuable in their work to improve environmental performance, prolong product lifetime, reduce energy use and waste disposal while boosting efficiency and increasing the use of secondary raw materials.

Over a product's complete life cycle, from design and production to its usage, disuse, and recycling, a DPP is a means to:

- increase a product's sustainability by addressing consumers' needs more effectively for longer, with less primary resources and energy required and less waste disposed of throughout the product's life cycle,
- achieve an increasingly circular economy by enabling the identification of opportunities to reuse, repurpose and recycle a product's components and wastes, as well as minimizing energy consumption throughout its life cycle,
- provide sufficient product locality information to assess manufacture, repair, and reuse transport and distribution energy use across the product life cycle, and
- provide sufficient insights to producers to assess mass production models against less resource and waste-intensive business models (e.g., service-oriented sustainable models).

To achieve this, the ESPR and its Annexes outline required information parameters linked to a DPP data carrier as appropriate, a summary of which is listed in Table 8.1.

Article 12 of the ESPR also states that a European Registry of all ESPR DPPs is to be established by the European Commission where economic operators are obliged to upload required minimal DPP data.

The DPP definition explicitly states the intent to enable broader voluntary data sharing through decentralized networks of value chain participants, going beyond the products and requirements regulated under the ESPR.

**Table 8.1** Required information parameters for DPP data carrier (collated from ESPR Articles (European Commission, 2022b) and Annexes (European Commission, 2022c))

| ESPR annex | ESPR article | Parameter | Expressed through (some may vary by product group) |
|---|---|---|---|
| III a | 7(2)b(i) | Durability/reliability | Mean Time Between Failures (MTBF), expected lifetime, performance |
| | 7(2)b(ii) | Ease of repair/maintenance upgrade/reuse | Information for end users on modularity, availability and ID of parts; materials, tools and processes for (dis)assembly |
| | 7(2)b(iii) | Ease and quality of recycling | Information on disassembly, recycling, or disposal at end-of-life |
| | 4 | Production of waste/energy and water consumption | Amount and type of waste produced/ resources consumed |
| | 8(2)b,c | Types of data carrier used and presentation details | QR code, Bar code, RFID, etc. and location (on product, packaging, etc.) |
| | 8(2)d | DPP corresponds to model, batch, or item level | ISO 15459 identifiers |
| | 8(2)e,f,g | Differentiated access to information within DPP | DPP attribute-based access control of DPP information and typology of agents |
| | 8(2)h | Period for which the product passport shall remain available | DPP duration of availability |
| III b, c | | Unique product identifiers | ISO 15459-6 identifiers |
| III d, e, j, k | | Regulatory compliance data and import, distribution, safety identifiers | TARIC (European Commission, n.d.-a) codes, conformity certificates, EORI number (European Commission, n.d.-b) economic operator contact details |
| III f | | User manuals, instructions, warnings, safety instructions | |
| III g, h, i | | Unique manufacturer, operator, facility identifiers | ISO 15459:2015 identifiers for agent roles and physically located facilities |
| | 10(g), 12(2)a | Data authentication, reliability and integrity shall be ensured | Strong cryptographic measures |
| | 10(h), 12 | DPPs designed and operated with a high level of security and privacy | A central EU DPP registry is to be established |
| | 10(a) | ESPR DPP interoperability | All EU-regulated DPP types must be interoperable in technical, semantic and organizational aspects of end-to-end communication/data transfer |

#### 8.1.1.2 What a DPP Should Not Provide

To further the ecodesign goals, the ESPR and its Annexes also outline information parameters that should not be linked to a DPP, outlined in Table 8.2.

An ESPR-compatible DPP only guarantees sufficient details of a product life cycle to satisfy ecodesign principles as framed in the EU regulatory framework. Although the

**Table 8.2** Parameters that should not be linked to a DPP

| ESPR article or annex | Summary |
|---|---|
| 5(5)e | No proprietary technology imposed on any agents |
| Annex I e | No technical solutions detrimental to re-use, upgrade, repair, maintenance, refurbishment, remanufacturing and recycling of products and components |
| 10(h) | Privacy must be ensured with DPP linked data access adhering to GDPR and other privacy regulations |

scope of the ESPR framework explicitly enables and promotes DPPs as an open data sharing environment, DPPs that are accepted within the EU DPP central registry are not guaranteed to contain consistent product information beyond this scope.

### 8.1.2 Graph Data and Resource-Event-Agent Accounting Method

In our research and development, we use a Resource-Event-Agent (REA; McCarthy, 1982) accounting model to create a product's DPP. According to this model, a resource undergoes transforming events operated by agents. An example could be the following: a designer (agent) produces (event) a design (resource), and a manufacturer (agent) uses (event) the design (resource) to produce (event) a bike (resource).

The REA accounting model structure allows for graph data representation. We implement this structure utilizing a graph database and the Graph Query Language (GraphQL) to access it.

When looking at concrete implementations of a DPP, we introduce the following two concepts (Valueflows, n.d.-c):

- To **trace** a resource: "follow the completed path backwards from its current point to where it began" – for example, tracing a bike from its current state through the production process back to the constituent components/materials.
- To **track** a resource: "follow the emerging path forwards from your starting point to wherever the thing is"—for example, tracking a bike's repairs and owner changes after being sold.

In our research and development, we focused primarily on tracing for the DPP because tracing contains each event that contributed to the manifestation of a resource, along with events of intermediate resources and their respective agents. For example, a bike's trace starts with the bike and goes back along the assembly phase, listing the parts used. It proceeds following the trace of the parts bought by a workshop from different resellers, which in turn had bought batches from other manufacturers, and so on. Such a DPP allows for a tracing of a resource from its current manifestation back to its origins, up to and including all raw materials used.

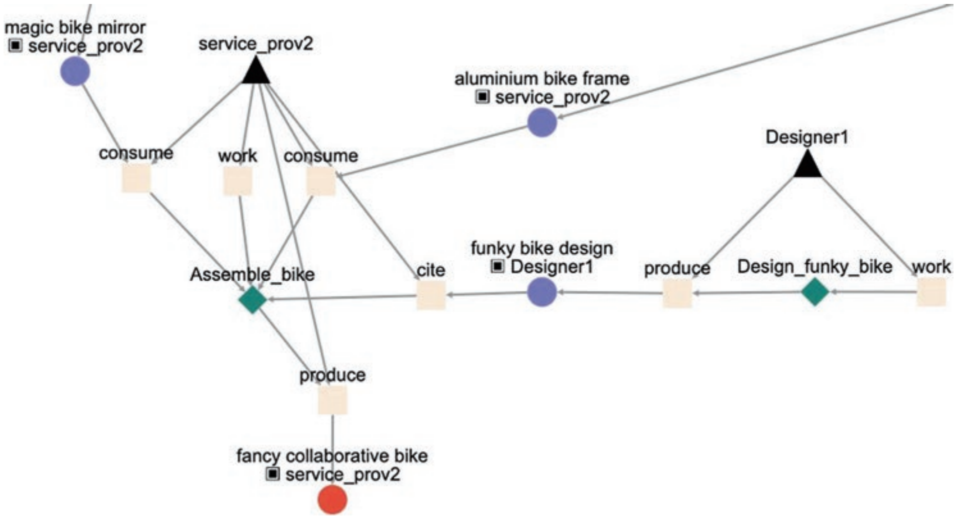


**Fig. 8.1** Trace (fragment) of "fancy collaborative bike" (at the bottom). Squares represent events, circles resources, and triangles agents. The graph represents Processes (group of events) using diamond glyphs

In other words, tracing captures the provenance of the resource – the chain of relations between resources, events and agents and their properties that constitutes a given manifestation of the resource. An example of tracing back a resource is depicted in Fig. 8.1.

As already mentioned, tracing represents a resource's causal paths. In the resulting graph data structure, each connection between resources and events, or events and processes, has a direction. This is consistent with the causal order of the events.

Concerning tracking, we will briefly mention that it can be used to see what byproducts are generated during the process of a particular resource. In our example, possible questions that tracking can answer are:

- What was also produced by the manufacturers that made the bike parts?
- What was made with the same raw materials used to make the bike parts?

We consider these questions less relevant for our present open hardware DPP use case but may revise this assumption in future research.

### 8.1.3 Valueflows: A REA Implementation

#### 8.1.3.1 Short Introduction to Valueflows

Valueflows, (n.d.-a) is a REA vocabulary to model economic resource creation, distribution, and exchange. Valueflows provide terms that can formally describe how a re-

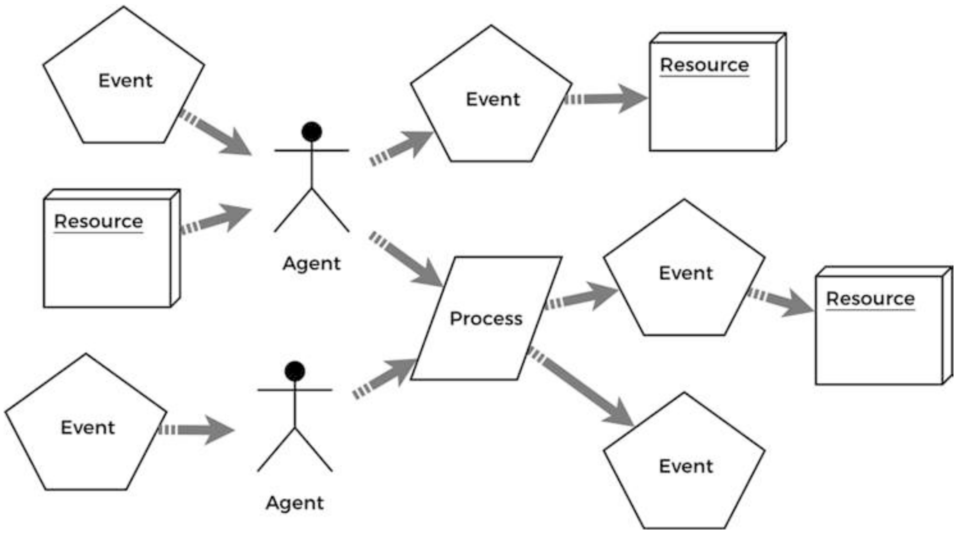


**Fig. 8.2** REA model relationship diagram

source is created and elaborated. For example, Valueflows is able to model how all agents produce a final product using their resources through a series of events.

The vocabulary models into a flow the sequence of events performed on resources by agents. The Valueflows standard specifies events by a set of possible actions they perform (produce, consume, etc.) and the effect each action has on the resources (produce generates a new resource, consume deletes one, etc.). A Process can group more events to develop a complex transformation on one or more resources, involving more Agents, over a defined span of time (see Fig. 8.2).

Valueflows has three levels: the level we just described models past events claimed to have occurred. There are two more levels: the second level models future plans (intents) and the other models present knowledge (including the know-how required to perform the events). While all levels are relevant, in this article we concentrate on past observed events, since this is directly relevant to DPPs in our experience so far.

#### 8.1.3.2 Advantages of a Valueflows-Based DPP

To examine how appropriate Valueflows is to model relations relevant for a DPP, we look at the conditions described in the tables in Sect. 8.1.1.1.

According to 5(5)e, proprietary solutions are not allowed in a DPP, meaning that a DPP must document all information in an open, standard, inter-operable format and machine-readable, structured, and searchable format. Valueflows satisfies these requirements because it is formulated as a standard, and it specifies its data format in a machine-readable form (Valueflows, n.d.-c).

Moreover, Valueflows facilitates accounting for different levels of granularity, i.e., at the model level (e.g., electric bike model AAA), batch (e.g., electric bike model AAA, produced in factory XYZ), or item (e.g., electric bike model AAA, serial number 123456789) as required by 8(2)d.

Article 10(a) states the requirement for each DPP to be fully interoperable with other DPPs. This can also be satisfied by Valueflows because of its formal specification that allows mapping its concepts to different formally specified semantics. In other words, Valueflows can be integrated with other ontologies.

Further, we observe the following two requirements:

- **Access rights** (8(2)e,f,g): the access to information included in the passport needs to be regulated
- **Product passport registry** (Article 12): a registry managed by the EU Commission receives sufficient info to authenticate DPP information. All the attributes (including the more confidential information) remain with the economic operator.

These are not tasks that a vocabulary can satisfy, but such requirements on top of Valueflows could be implemented because its attributes can have links to external data (URIs – Uniform Resource Identifiers) as values, allowing the distribution and protection of information.

Finally, we will discuss more about the requirement for "data authentication, reliability and integrity" (10(g)) in the context of cryptographic signatures.

#### 8.1.3.3 Requirements for Authentication in DPPs

In OSH development, multiple parties can be involved in producing a particular resource, a condition common to most supply chains. Parties should be able to work together with limited trust and visibility of each other's actions. Each party then certifies and assumes liabilities for its part of the flow (corresponding to a sub-graph of the entire trace graph in our data representation), and each party can see and verify the other parties' actions.

We use Fig. 8.1 as an example, where agent Designer1 creates a design (right part of the picture), releases it licensed as an OSH design; agent service_prov2 then uses ("cite" in Valueflows) this design and uses (i.e., "consumes") two other resources (magic bike mirror and aluminum bike frame) to produce a bike (fancy collaborative bike). If we imagine a customer wanting to buy a bike designed by a local designer: the DPP can show this, but why would the customer trust it? A service provider may falsify a DPP, claiming they used an OSH design from a local designer.

A way to guarantee the authenticity of such claims is the use of cryptographic signatures. In this example, first, Designer1 generates (and thus signs) the design's DPP (represented by the sub-graph on the right side of the picture). Once the bike is built from the design, service_prov2 generates (and thus signs) the manifested bike's DPP (which includes citing the design of the local designer).

As shown in Fig. 8.1, the bike's DPP contains the DPP for the bike's design, as the design is embedded inside the bike's trace graph. This configuration implies that when service_prov2 generates the bike's DPP, the sub-graph describing the design is identical to the subgraph signed by Designer1; otherwise, Designer1's design use cannot be verified.

A requirement for the DPP then becomes the following: any DPP generated at time t needs to include any DPP generated at an earlier time ti. In other words, each DPPt is a subgraph of DPPti if t ≤ ti.

We will focus on this requirement to discuss two possible limitations of a Valueflows-based DPP.

#### 8.1.3.4 Implementation Limitations of Using Valueflows for a DPP

During a trace, we rewind time and retrieve all the events, resources, and agents relevant to the resource we are tracing. Therein, we expect to find previous states of resources and agents as we trace back in time.

Currently, Valueflows does not explicitly have the concept of a resource (or agent) at a particular time or before a specific event. Therefore, different "states" of the system are not explicitly modelled nor stored. Consequently, we cannot assume that the past state of a resource or an agent can be retrieved when tracing back: only the current state of a resource or agent is stored. The limitation to present state means that mutable attributes of a resource or agent that may be saved and exported in a trace may not be equal to what they were at each point in time referred to in the trace. A resource might have been moved in the meantime or consumed – it might therefore have a different quantity.

Past states of a resource or agent might be retrieved by looking at events which are conceptually immutable and therefore do not need a state. Examining events may be a viable solution, but care must be exercised since events may also be added to past processes, for instance, to correct mistakes in the model a-posteriori. This might be a problem, depending on where the correcting event is present in the trace, which is temporally (possibly much) later but logically next to the "corrected" event. Placing it next to the corrected event in the trace would invalidate the requirement we introduced before, i.e., traces (and therefore DPPs) at earlier stages must be a subset of traces at later stages.

#### 8.1.3.5 Ways to Overcome Valueflows Limitations

There are several options for maintained consistency between DPPs generated at different times. One is to rely only on immutable data, for example, attributes that events cannot update. Attributes of a resource that can change in time should be excluded from the DPP and, if needed, derived from the applied changes (the events) starting from an initial, known situation. This solution assumes that event flows do not change, as discussed in the previous section.

A more comprehensive solution is to enforce immutability by technical means, adopting immutable storage as a backend for Valueflows, such that any change is recorded in 'append-only' mode. This way a DPP generated at later stages would always contain DPP generated at earlier stages in its revision history, making it possible to go back to a point in time and generate the same DPP.

### 8.1.4 DPP Verification Methods

Proper means to verify the authenticity of a DPP are essential because DPP-linked data references need to be exported into a data carrier (for instance, a RFID tag or QR code) and rely on a verification method to assess the data carrier's integrity. The latter can hold only a limited amount of data constrained by the physical data carrier format, and so contains linked data references to provide further details for online verification.

An offline verification method can cryptographically verify the direct data and references contained inside the data carrier. An online verification method can verify both the data carrier content as well as all details of the referenced linked data available online. This link is necessary for an import of data into another federated system or a visualization of details for closer inspection.

In the case of Open-Source Hardware DPPs, it is crucial to have some information about agents involved in a product life cycle to further serve the implementation of economic models. In some situations, the agents should also produce valid signatures to attest liabilities and warranties related to an object's production (such as service_prov2 in Fig. 8.1). Yet, strong privacy concerns arise then in terms of protection of personal details of people contributing work to a design, product, or service.

This configuration calls for the development of an advanced cryptographic model that can solve these requirements and which serves to authenticate data carrier linked data references to federated graph data storage. We have already created the cryptographic primitives for such a model in REFLOW crypto (Roio et al., 2021).

The building blocks are twofold: **BLS signatures** (Boneh et al., 2022) because of the possibility to aggregate them to pack multiple signatures into a single seal; this way, it can be exported at a reasonable size for non-interactive verification. **Zero-Knowledge Proofs** because they preserve agents' privacy while proving they are known members of a production lab, which may give access to further details about the production process.

It is beyond the scope of this article to formally define a signature scheme. We experimented with this approach in-vitro and in-vivo with demonstrable benefits, especially when we tailored a signature to the specific needs of a single group of designers and manufacturers or a federated network of production labs.

## 8.2 Final Considerations

The Valueflows vocabulary as a Resource-Event-Agent accounting system is instrumental in the description of the complex graph of relationships behind the design and production of Open-Source Hardware. It can also go a long way in facilitating advanced authentication schemes that result in compact verifiable offline seals when properly adapted to a specific domain. It also eases the task of describing a production flow at scale when federation becomes necessary to account for multiple agents belonging to different organizations. The findings of research have been implemented into a software application called Zenflows (INTERFACER, n.d.-b), which can be adapted to more domains needing to handle data quality and complexity using REA accounting.

What we have learned so far is that it is necessary to implement Valueflows in a system that supports accounting for state changes in the time dimension and provides a history similar to that offered by revisioning systems, as for instance Git does for software.

It is also necessary to couple Valueflows with an additional ontology that goes further into detail to describe the properties and attributes of nodes in the graph. When modelling Open-Source Hardware production, the options for additional ontologies are neither scarce nor challenging to integrate; for instance, adopting a licensing classification like the one provided by the REUSE (n.d.) project is advisable.

As a future research outlook, we plan to harmonize these new modelling directions with existing initiatives such as the European Data Spaces (https://joinup.ec.europa.eu/collection/semic-support-centre/data-spaces), in order to be able to contribute to the "single market for data" as advocated for by the EU to ensure global competitiveness and data sovereignty" (European Commission, 2023). As a further ambitious application of ESPR ecodesign principles, the OSH DPP should be examined in the broader context of tracing electronic waste (Your Europe, 2023).

We are confident that the participatory approach of this research, grafted in the tradition of free and open-source software and knowledge commons, is the best methodology to co-develop the technical tools and the cultural and social background that enable regional initiatives to focus on information-intensive initiatives aimed at reusing designs and materials to boost local production. Our cooperation with the Fab City initiative is ideal to further pilot our concepts and continues well beyond this regionally focused beta release with a planned global deployment of our software as a FabCity Operating System to be launched during 2023.

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# 9 The Fab City Index

## A Toolkit for Measuring Progress Towards a Circular Economy

Niels Boeing

## 9.1 Introduction

Fab Cities have set themselves an ambitious goal: by 2054, they want to have completed their transformation to a full circular economy according to the DIDO-Paradigm (Diez, 2018, p. 13). That means that they have to produce everything that is consumed within their borders by themselves, they neither import raw materials nor export any waste, nor do they emit greenhouse gasses above a sustainable level. Only data is imported or exported. Thus, material input to production has to come from inside the city by means of urban mining, recycling, upcycling or re-use. So, the circular economy is even more ambitious than just a (re)localized economy that could still import raw materials and would only focus on manufacturing within city limits. Obviously, no city in Europe, and certainly no big city with a population over half a million inhabitants, is anywhere near such a fully circular economy today. Quite on the contrary, since five decades of de-industrialization have left many European cities with a dwindling manufacturing capacity (Rowthorn & Ramaswamy, 1997; Kollmeyer, 2009; Škuflić & Družić, 2016). A great deal of goods must be imported. Manufacturing has moved offshore, and so has production in general if we include food and energy resources. And yet, the production base has to be rebuilt if Fab Cities are to accomplish their 2054 goal.

However, it is not self-evident what production capacity has to be rebuilt exactly. So, in addition to spurring innovation in digitization, production machinery and recycling capac-

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ity, a Fab City needs to evaluate where it stands on its way to a fully circular economy. Which production sectors are strong and economically sound, which are underdeveloped or even missing? To assess the state of a Fab City on its way towards the 2054 goal, a measure – or a toolkit of measures – would be needed.

The first Fab City to address the need for such measures has been Grand Paris, together with consulting firm Utopies. In 2018, they introduced the concept of the Fab City Index (Florentin et al., 2018). It comprises three sets of measures: the priority of an economic sector in a Fab City's strategic agenda, its self-sufficiency with regards to the 2054 goal and the index number itself, which can attain a value between 0 and 100. 0 means: nothing is produced within the city boundaries; 100 means: the urban economy is fully circular, nothing has to be imported (and no waste to be exported). This index number aims to make progress in the comparability of different Fab Cities and incentivize them to step up efforts in building a circular economy.

Unfortunately, the Fab City Index as conceived by Fab City Grand Paris and Utopies is closed-source. There is no documentation yet on how the index value is calculated nor which data are being used. That means that other Fab Cities cannot replicate the analysis on their own. Given the centrality of the open-source paradigm for the Fab City concept, the sub-project WP 3.3 of the INTERFACER project thus aims to develop a framework for an "open-source Fab City Index" that could be applied independently by other Fab Cities, at least in Europe. In the following, we propose such a framework by taking the city of Hamburg as an example.

### 9.1.1 Theoretical Motivation

Indexes have long been in use to capture the change of state of an economy or a society over time and make it comparable to other entities. One well-known example is the consumer price index. It collects price data for numerous goods, from a representative market basket in a given year in a standardized way and records their price increases against the previous year. Goods are grouped in categories, the price increase of which are given individual weights that reflect their demand and everyday consumption, thus their current relevance. The weighted price increases of the categories are summed up and yield the index number, i.e., the aggregated price increase over all categories against the previous year (or the base year).[1] The increase marks the inflation rate. If, for instance, the index value for the current year is 1.09, the market basket is 9% more expensive than in the previous year. The weighting is important because different categories of goods experience different price increases that are individually insignificant but matter in aggregation.

[1] Technically, it is then compared to a base year that is reset every five years.

Another example for an index number is the Gini Coefficient, which is an index for the degree of inequality in the distribution of a country's income or wealth. Mathematically it is not a sum but the ratio of two geometrical areas that represent distributions of wealth in the population. The index number can attain values between 0 and 1, wherein 0 marks perfect equality, 1 stands for maximum inequality, meaning one individual owns the country's whole wealth. The Gini Coefficient is used to compare the degree of equality between different countries and can thus, given equality is a societal value, inform policy-makers to take measures against rising inequality if the index value rises over a longer period.

In a similar way, a Fab City Index could be developed that aggregates the development of local production and recycling capacities of a city's economic sectors into a single number. With it, a Fab City's progress over time can be quantified and made comparable to other cities. At the same time, it can provide a more detailed look into a city's development towards a Fab City because, analogous to the consumer price index, it requires a thorough analysis of individual economic sectors. Here, a typical measure for local production capacity in a certain sector could be the share of a product in local demand that could theoretically be manufactured in a Fab City. If, for instance, a Fab City can produce half the number of new cars that are bought throughout a given year, the share and thus the measure of the respective sector is 50%. To make results comparable across different Fab Cities the measures should follow standardized classifications of economic sectors or categories of goods: for the production side, statistics are ordered according to the NACE classification scheme that was introduced for national economic statistics in the EU in 2006 (European Commission, 2008)[2]; for the consumption side, statistics follow the COICOP classification (United Nations, 2018).[3] With these measures, institutions and agencies that advance the Fab City concept would be able to make informed decisions for which economic sectors and categories of products they would have to step up efforts in order to reach self-sufficiency.

## 9.2 The French Concept

To calculate an ideal Fab City Index and assess the state of different economic sectors, it would require complete and exact data on production and consumption within the urban territory. For instance, how many sneakers, washing machines or other goods have been bought and how many of them have been manufactured inside the Fab City limits? These data do not exist yet. There is no count of individual items manufactured and bought over

[2] Regulation (EC) No. 1893/2006. NACE stands for the French term "nomenclature statistique des activités économiques dans la Communauté européenne". The German equivalent is WZ 2008 (WZ for "Wirtschaftszweige").

[3] COICOP stands for "Classification of Individual Consumption According to Purpose".

**Table 9.1** Macro-sectors

| | | |
|---|---|---|
| - Agriculture, fishing industry<br>- Extractive industries<br>- Forestry, woodwork<br>- Mineral construction materials | - Metal industry<br>- Machines/equipment<br>- Other manufactured goods<br>- Food and beverages | - Fashion, textile<br>- Paper, cardboard, printing<br>- Chemistry<br>- Plastic, rubber |

the course of a year. Thus, the Fab City Index concept as conceived by Fab City Grand Paris and Utopies works with an indirect modeling approach which draws on several databases about, among others, economic data of companies, household income, imports and exports. The LOCAL SHIFT model developed by Utopies analyzes 257 sectors which are aggregated to the following 12 macro-sectors in Table 9.1.

Each macro-sector is assigned a value between 0 and 10 for two dimensions: level of self-sufficiency and level of priority. Self-sufficiency means "the territorial entity's capacity to cover local demand for a given sector", while priority indicates a "sector's strategic importance with regard to local demand". The results for all sectors are finally aggregated into a final score between 0 and 100 which is the index number. A score of 100 means that a Fab City has reached the state of a fully circular economy and can produce its entire demand by itself. For Paris, a Fab City Index of 37.58 in 2018 and a level of self-sufficiency of 8.7% has been calculated (Florentin et al., 2018).

While this approach is truly pioneering work, it has three shortcomings: firstly, the LOCAL SHIFT model is closed source. How and under which assumptions the data is processed is not revealed, thus other Fab Cities cannot replicate the analysis themselves. Secondly, the 12 aggregated macro-sectors represent the divisions of the NACE classification too closely. On the urban level, extractive industries – like oil production – and mineral construction materials are either not that relevant or simply nonexistent. On the other hand, NACE division C26, Manufacture of computer, electronic and optical products, is probably subsumed under Machines/Equipment, which does not match its importance for an urban economy in the early twenty-first century. Also, "Repair" and "Recycling" are absent in the 12 macro-sectors, though both would be of utmost importance for a circular economy. Thirdly, it is unclear whether and how consumption enters into the model.

## 9.3 The Hamburg Approach

According to the Fab City Global Alliance's emphasis on an open-source approach towards production, documentation and operations, it would be important that these measures be based on openly accessible data. Thus, we suggest an alternative approach that draws on data publicly available for Hamburg. Though these data are far from being complete, they enable us to make a first assessment of where Hamburg stands with regards to becoming a Fab City.

However, the NACE classification has inherited a Fordist perspective on the economy, which is heavily extractive in its production of resources and gives much weight to classical industrial sectors like the construction of machinery including vehicles of all sorts. However, the rationale of a Fab City's circular economy should not be to just replicate the current system of manufacturing and consumption with local means. It has to take into account that the current system is inherently unsustainable because it relies too much on extraction and growth of output. At the same time, the shift of major European cities towards an economy centered around services which use digital technologies today in one way or the other needs considering. Thus, we suggest 16 macro-sectors that partly differ from the aggregation in the French approach. These sectors are shown in Table 9.2. For each sector corresponding metrics and/or relevant NACE divisions or groups are given.

**Table 9.2** 16 macro-sectors which have to be monitored for measuring the progress towards a fully circular economy

| | Macro-sector | Metric | NACE |
|---|---|---|---|
| 1 | Energy | MWh/TJ renewable | (D35) |
| 2 | Water | Groundwater supply in Mio. $m^3$ | (E36) |
| 3 | Agriculture and fishing | Global hectares | A01, A03 |
| 4 | Food and beverages | Production value vs. consumption expenses in € | C10, C11 |
| 5 | Forestry and products of wood | [Estimate] | A02, C16, C18. |
| 6 | Textiles and clothing | Production value vs. consumption expenses in € | C13, C14, C15 |
| 7 | Chemical products | Production value vs. consumption expenses in € | C19, C20, C21, C22 |
| 8 | Extractive industries, mining and quarrying | Biomass production (no fossil or mineral deposits) | B5, B6, B7, B8 |
| 9 | Metal industry | Production value vs. consumption expenses in € | C24, C25 |
| 10 | Machinery and equipment | Production value vs. consumption expenses in € | C27, C28 |
| 11 | Vehicles and transport equipment | Production value vs. consumption expenses in € | C29, C30 |
| 12 | IT and communication | Production value vs. consumption expenses in € | C26, C18.2 |
| 13 | Other manufactured goods | Production value vs. consumption expenses in € | C23, C32 |
| 14 | Construction | Number of companies | C41, C42, C43 |
| 15 | Repair | Production value vs. consumption expenses in € | C33, G45, S95 |
| 16 | Waste and recycling | Amounts in t | (E37, E38, E39) |

## 9.4 Data Sources

Concerning energy, data are available from the Statistical Office for Hamburg and Schleswig-Holstein,[4] concerning water, from the local provider Hamburg Wasser.[5] Concerning productive sectors, we draw on data for agriculture and for manufacturing sectors as they are being annually collected by the Statistical Office.[6] Data concerning waste collection comes from the Hamburg Department of the Environment, Climate and Energy.[7] Concerning recycling data, we rely on numbers given by Hamburg's Department of Sanitation[8] as well as the Statistical Office.[9] Data in greenhouse gas emissions come from the Statistical Office.[10]

Concerning private consumption, data are available from the 2018 Survey of Consumption Expenses of Private Households conducted every five years by the Statistical Office for Hamburg and Schleswig-Holstein.[11] This is the only direct data collection on consumption that is publicly available. Concerning company consumption, we use data about investments in the manufacturing sectors.[12]

In addition, to give a rough breakdown of material flows for Hamburg, we use the Raw Material Consumption numbers for Germany from Eurostat which were calculated by the Institut für Energie und Umweltforschung ifeu (institute for energy and environmental research) in Heidelberg (Schoer et al., 2021). Concerning ecological footprints in global hectares, we use numbers from the respective study of the Zukunftsrat Hamburg (future council) conducted in 2012 (Zukunftsrat Hamburg, 2012).

While the data for energy, water, waste and recycling can be directly analyzed, data for production and consumption have to be matched whenever possible. Production data is grouped according to NACE codes, private consumption data according to COICOP codes. For this purpose, we have built a concordance table between NACE codes and

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[4] The series *Energiebilanz und $CO_2$-Bilanzen für Hamburg*.

[5] Hamburg Wasser annual reports.

[6] These are mainly the statistical reports series C I 3 *Der Anbau von Gemüse und Erdbeeren in Hamburg*, i.e., production of fruits and vegetables, and C III *Die Viehwirtschaft in Hamburg*, i.e., livestock production, for agriculture, and E I 5 *Die Produktion des Verarbeitenden Gewerbes in Hamburg*, i.e., manufacturing.

[7] The series *Siedlungsabfälle in Hamburg*.

[8] The series *Umwelterklärung*, the annual environmental report, and *Stadtreinigung Hamburg. Daten und Fakten*.

[9] The series Q II 4 *Erhebung über die Aufbereitung und Verwertung von Bau- und Abbruchabfällen in Hamburg* specifically for construction waste.

[10] The series *Energiebilanz und $CO_2$-Bilanzen für Hamburg* and the series Q V 3 *Klimawirksame Stoffe in Hamburg*, i.e., other climate-relevant substances.

[11] The classification of consumer expenses in this survey still follows SEA-CPI 2013. In 2021, SEA-CPI was made congruent with COICOP (Statistisches Bundesamt, 2021).

[12] The series E I 6 *Investitionen im Verarbeitenden Gewerbe sowie im Bergbau und bei der Gewinnung von Steinen und Erden in Hamburg*.

COICOP codes because we want to a) estimate what fraction of demand a sector could theoretically produce, and b) weight different sectors according to the weighting scheme for the consumer price index calculations. As Ganglmair and colleagues correctly noted, concerning consumers, "not all industries are equally relevant", and they have built a similar concordance table for the calculation of price markups (2020), which can be found in the annex.

The weighting scheme for the consumer price index is a well-founded tool that has long been in use for measuring inflation (Statistisches Bundesamt, 2019). It reflects the relevance of groups of goods and services for consumers, i.e., citizens. All weights are given in per mille and add up to 1000. After matching production data with consumption data via the concordance table, only weights are used where a matching of data is possible. These weights can be adjusted so that they add up to 1000 again, and then be used to calculate the index number. Hence, we could get a first estimate of a "consumption-based" Fab City Index.

The Hamburg Chamber of Commerce has provided a geographical breakdown of companies classified according to NACE categories for the seven districts of Hamburg. It allows for an identification of where certain (sub)sectors in the city are clustered. If aligned with the groups of goods for the consumer price index by use of the concordance table, this makes the depiction of the number of manufacturers for a certain group of goods possible, if there are any at all.

## 9.5 Preliminary Results

Data are evaluated for the year 2019 because this was the last year before the Sars-CoV-2 pandemic distorted the economy. It is important to understand that matching production value and consumption expenses through the concordance table can only reveal what potential production capacity there is compared to its demand. The numbers do not indicate that a certain sector is manufacturing the very goods that are actually consumed in Hamburg. It indicates that there would probably be enough machinery and equipment (and expertise) to shift production to goods that would meet the local demand. This matching is tenable because production data are given in production value (that is annual production capacity in market prices minus several taxes like alcohol tax and customs – not revenue), whereas the consumption expenses are given in household money spent (that is market prices, from which VAT has to be deducted). So, both data sets are market price data.

Though the project is incomplete as of now, some insights are already available. Some macro-sectors are at a good starting point for the requirements of a circular economy because they already show a significant capacity to match local demand: **Macro-sector 4**, food and beverages, can be assigned a manufacturing capacity of roughly 50% of the local demand. The construction sector is quite strong, accounting for more than half of the companies registered with the chamber of commerce. This is no surprise given the amount of construction – and demolition – projects in Hamburg.

**Macro-sector 13**, other goods, could meet over 60% of local demand if we match production value for NACE class C32 with private consumption expenses in COICOP groups 05.1, 05.4, 05.5, 05.6, 09.2, 09.3 and 09.5 (furniture, recreational goods plus groups of semi-durable and durable goods for households).

**Macro-sector 10**, machinery and equipment, has a strong base with an annual production value of more than 2.6 billion Euro which is considerably higher than the local investments in machinery and equipment by Hamburg manufacturers in 2019.

**Macro-sector 7** is another strong one, chemical products. The manufacturing capacity especially for pharmaceutical products is very high based on production value data. Actually, it produces more than the local demand inferred from consumption data.

However, some of the macro-sectors are quite weak: Though there are some strong players in **macro-sector 12**, IT and communication, these are specialized semiconductor manufacturers that do not produce consumer devices like personal computers or smartphones and could not easily switch production to these devices high in demand.

Naturally, lacking deposits inside the city limits, **macro-sector 6**, fossil fuels and mining and quarrying, is nearly completely dependent on imports. The high production value for NACE division C19, manufacture of coke and refined petroleum products, of more than 1.8 billion Euro in 2019 is only possible because Hamburg as Germany's biggest port is a highly important trade center for crude petroleum.

**Macro-sector 11**, vehicles and transport equipment, comprises some 190 companies, none of which is one of the big car manufacturers. The one exemption in the vehicle sector is the Airbus aircraft plant that is responsible for roughly a quarter of Hamburg's export turnover.

**Macro-sectors 1 and 3**, energy and agriculture/fishing, are evidently weak because the share of renewables in energy production is still low, while agricultural land is in short supply. Compared to the area of 9.1 million global hectares needed to feed a population of 1.84 million (Zukunftsrat Hamburg, 2012), the land area used by agriculture is less than 15,000 hectares. Figure 9.1 shows a summary of the preliminary results.

Now that we have preliminary self-sufficiency levels for each macro-sector, we have to assign weighting factors to each of them. For some macro-sectors, we can use the weighting factors from the consumer price index where consumption expenses have been recorded. For others we rely on an informed guess as of yet. Table 9.3 shows the weighting factors that could be used for a first index number calculation.

From these weighting estimates, we would get a Fab City Index value for Hamburg of 37 on a scale between 0 and 100. However, the weighting factors require further discussions as we will show in the next section.

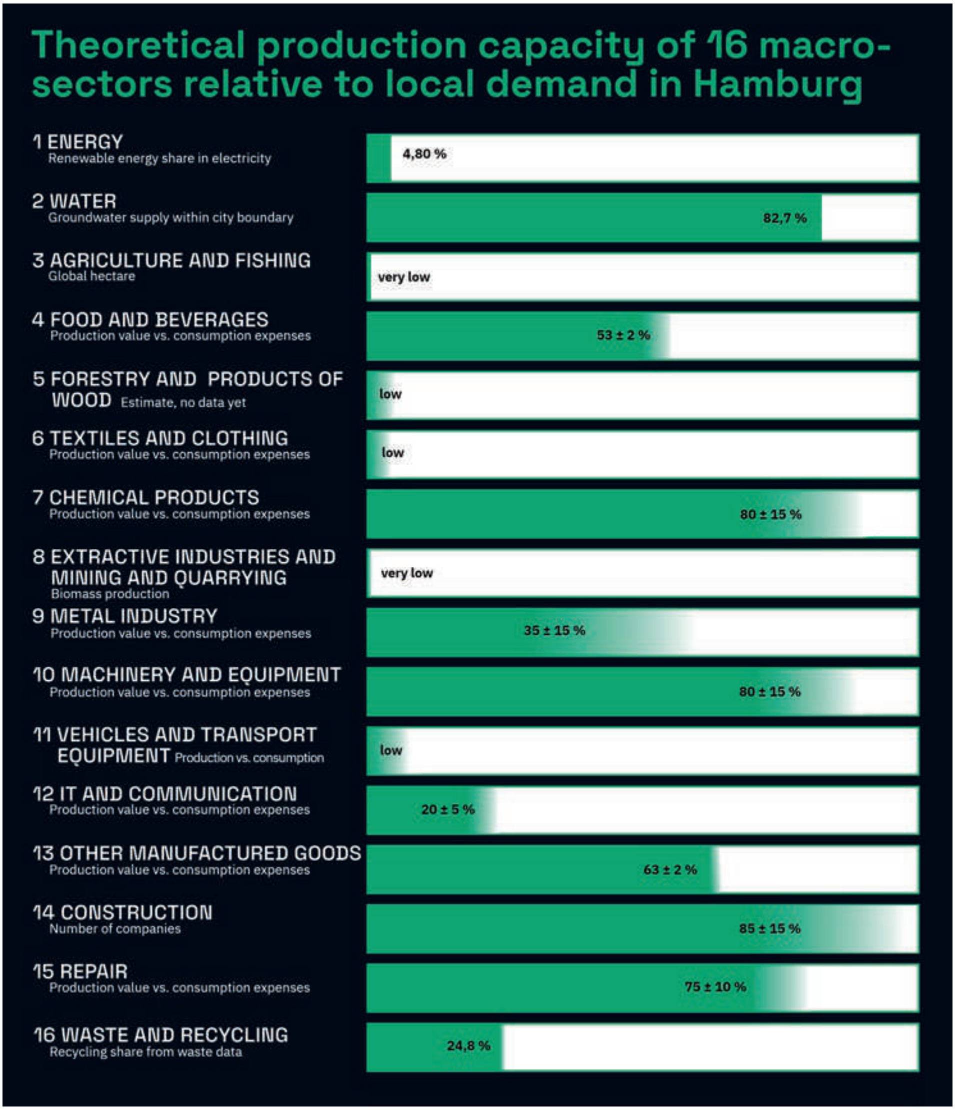


**Fig. 9.1** Each macro-sector has a bar that runs from 0 to 100% local production capacity. The blurring of the actual preliminary value indicates the uncertainty of that current value

**Table 9.3** Weightings in the fourth column come from weightings of consumption expense categories that were applicable to the calculation. Weightings in the fifth column are estimates for sectors where no consumption data are available as of yet. Weights in both columns are given in per mille and add up to 1000

| | Ratio production/consumption | Basis of ratio | Weighting according to CPI schem, if applicable, in ‰ | Weighting estimate in ‰ | Weighted rates | NACE / WZ2008 divisions | Note |
|---|---|---|---|---|---|---|---|
| **Energy (renewable)** | 4,80 % | Mwh/TJ | 68,82 | | 0,0033 | (D35) | Weighting from COICOP 04.5 |
| **Water** | 82,70 % | Groundwater supply | 36,43 | | 0,0301 | (E36) | Weighting from COICOP 04.4 |
| **Agriculture and fishing** | 0,05 % | Global hectares | | 96,85 | 0,0000 | A01, A03 | Weighting estimate from COICOP 01 |
| **Food and beverages** | 53,87 % | Production value vs. consumption expenses | 134,62 | | 0,0725 | C10, C11 | Weighting from COICOP 01 and 02 |
| **Wood and products of wood** | 5,00 % | Estimate | | 27,08 | 0,0014 | A02, C16, C18.1 | Weighting estimate, includes COICOP 09.7 |
| **Textiles and clothing** | 0,42 % | Production value vs. consumption expenses | 49,29 | | 0,0002 | C13, C14, C15 | Weighting from COICOP 03 and 05.2 |
| **Chemical products** | 90,00 % | Estimate from production value vs. consumption expenses | 46,13 | | 0,0415 | C19, C20, C21, C22 | Weighting from COICOP 06 |
| **Fossil fuels, mining and quarrying** | 0,05 % | Biomass production, no deposits | | 30,00 | 0,0000 | B5, B6, B7, B8 | Weighting estimate |
| **Metals** | 50,00 % | Estimate from production value vs. consumption expenses | 74,25 | | 0,0371 | C24, C25 | Weighting from COICOP 13 |
| **Machinery and equipment** | 90,00 % | Estimate from production value vs. consumption expenses | | 74,25 | 0,0668 | C27, C28 | Weighting from COICOP 13 |
| **Vehicles and transport equipment** | 1,00 % | Estimate from production value vs. consumption expenses | 129,05 | | 0,0013 | C29, C30 | Weighting from COICOP 07 |
| **IT and communication** | 20,00 % | Estimate from production value vs. consumption expenses | 47,54 | | 0,0095 | C26, C18.2 | Weighting sums up from classes in COICOP 08 |
| **Other goods** | 63,41 % | Production value vs. consumption expenses | 50,04 | | 0,0317 | C23, C32 | Weighting from COICOP 05 |
| **Construction** | 100,00 % | Number of companies | | 37,77 | 0,0378 | C41, C42, C43 | Weighting estimate |
| **Repair** | 80,00 % | Estimate from production value vs. consumption expenses | 27,88 | | 0,0223 | C33, G45, S95 | Weighting from COICOP 04.3 and 07.2.3 |
| **Waste and recycling** | 24,80 % | Recycling share from waste data | | 70,00 | 0,0174 | (E37, E38, E39) | Weighting estimate |
| | | | 664,05 | 335,95 | **0,37** | | |

## 9.6 Discussion and Outlook

Though these insights already indicate which point a strategy for a circular economy should focus on, they only give a rough picture. Much more hard data is needed. The publicly available data suffer from several limitations: for one, legal restrictions. Production values are collected for companies with 20 or more employees. Data for 2019 is shown for 1246 companies in the series E I 5, while there are more than 17,500 companies classified by the chamber of commerce in the NACE groups in manufacturing, albeit most of them are small-scale enterprises. Unfortunately, production value is unavailable for all companies considered in the series. If a NACE group features only a low single digit number of companies and one of them has a huge market share in comparison to the others, the production value is not given due to the protection of competition. Otherwise, production values of the small companies could be inferred from the approximately known value of the big player. This regulation distorts the data.

Import and export data could principally help to clarify which sectors, and that is: which areas of consumption, are primarily dependent on imports. Unfortunately, transshipments in Hamburg's port distort this data. Imports are given for general trade,[13] i.e., goods that are not consumed in the city but go in stock and can stay there for an unknown amount of time, are not excluded from the import value. On the other hand, exports are counted as special trade,[14] goods manufactured or finished in Hamburg. So, the transit of goods is not recorded, thus we cannot infer the real balance of goods from the balance of import and export values. According to the Statistical Office, this makes Hamburg an exception compared to other federate states of Germany to date.

A third limitation is the aforementioned lack of comprehensive consumption data. In the regular consumer survey, expenses are inquired only for a limited number of goods, not the entirety of goods as listed in the COICOP classification. Thus, the numbers mostly apply to aggregated classes of goods like clothing and footwear, whereas the expenses, for instance, for household appliances are not collected. Given that household appliances constitute an important equipment for households – though not being replaced very often –, an average number would be helpful for a circular economy strategy that takes the local manufacturing of household appliances into account.

In general, the data being collected has a bias towards a traditional industrial policy which emphasizes output and growth rates, and which does not explicitly take sustainability issues into account, let alone the imperative of a circular economy. With respect to the requirements of the Fab City concept, the extent and reliability of environmental data meanwhile outmatches that of economic data, which is remarkable given that economic statistics have a much longer history.

[13] German: "Generalhandel".

[14] German: "Spezialhandel".

Whether the perspective of traditional industrial policy is taken or the perspective of a Fab City circular economy affects the priority of the macro-sectors which is reflected in the weighting scheme of the consumer price index. For instance, macro-sector 11, vehicles and transport equipment, currently has a high priority for the German economy in general because it is associated with jobs and exports as well as the aspiration of limitless mobility. On the consumption side, its weighting factor is quite high with a value of 129.05 per mille. In the future, its priority certainly has to decrease. Hamburg for instance has had a fleet of more than 950,000 vehicles – including 813,847 passenger cars – in 2021. A Fab City would not seek to constantly renew this fleet by adding thousands of cars each year. That means: The priority of a macro-sector and hence its weighting factor in the index calculation is not simply a question of statistics but an eminently political question. It has to reflect thresholds of sustainability. In the case of macro-sector 11: what is the sustainability threshold for urban mobility – concerning the number of private cars and the frequency of public transport services? Should a Fab City eventually be a bicycle city where car mobility becomes a rarity such that the manufacturing of cars is of minor importance? The answers to these questions will strongly affect the priority of macro-sector 11. The same holds for other sectors.

That said, the Fab City Index concept as introduced here is only a starting point. It can serve as a framework with which first assessments of a Fab City's development are possible in the next few years, but parts of the framework can and will change over time. The priorities, that is the weighting factors of the macro-sectors, have to be constantly reviewed. Even the suggested classification of the 16 macro-sectors is not fixed once and for all. Yet, without a structured framework for assessing the efforts towards a circular economy the road to the Fab City 2054 goal cannot be taken.

There is another caveat: the Fab City concept can probably not adhere to a city's territory in a stricter sense. Hamburg, being a federal city state in Germany, has the advantage of having data available on the city level. However, in the long run, the metropolitan region will probably be the more practical reference frame. It is not only the agricultural production of the surrounding regions that Hamburg relies on and cannot substitute easily. Macro-sector 2, water, gives another example: all drinking water in Hamburg is extracted from groundwater, but the groundwater supply inside city limits covers only 82.7% of its consumption. The rest is drawn from the surroundings, with secured water rights. Thus, Hamburg would have to reduce its water consumption. Regarding the increasing risk of droughts even in the rainy North of Germany, a reduction alone could perhaps not be enough to keep the city's water demand and the groundwater supply in balance. How the macro-sectors will develop and if the metropolitan region has to be included will require political decisions.

That does not change the fact that the advance of the Fab City concept should be accompanied by a refined data collection strategy. This will certainly not be implemented at short notice. However, more accurate and more relevant data would make the steps towards a fully circular economy more transparent. It could also help to spur innovation and make progress comparable across the Fab City network. Finally, it could coalesce with current efforts of some cities to implement dashboards that visualize environmental and/or smart city metrics. Fab City Hamburg e. V. plans to implement a “Fab City Dashboard” that would show key metrics as indicated above. This would not only help policymakers but companies and the general public alike to comprehend what is needed for a realization of the Fab City potential. Fortunately, a unified data framework at least for European cities is already at hand with NACE and COICOP classifications. More comprehensive data could substantially support the next steps.

## Annex

**NACE-COICOP concordance table for the main tiers of each system:**

Concordance table: matching NACE classes to COICOP classes

| NACE division | NACE/WZ English | NACE class | COICOP class | COICOP English | COICOP division |
|---|---|---|---|---|---|
| A01 | **Crop and animal production, hunting and related service activities** | **A01.1** | **01** | **Food and non-alcoholic beverages** | 01 |
| A01 | Growing of non-perennial crops | A011 | 01.1.1 | Cereals and cereal production | 01 |
| A01 | Growing of perennial crops | A01.2 | 09.3.1 | Garden products, plants and flowers | 09 |
| A01 | Animal production | A01.4 | 01.1.2 | Live animals, meat and other parts of slaughtered land animals | 01 |
| C10 | **Manufacture of food products** | **C10** | **01** | **Food and non-alcoholic beverages** | 01 |
| C10 | Processing and preserving of meat and production of meat products | C10.13 | 01.1.2 | Live animals, meat and other parts of slaughtered land animals | 01 |
| C10 | Processing and preserving of fish, crustaceans and molluscs | C10.2 | 01.1.3 | Fish and other seafood | 01 |
| C10 | Processing and preserving of fruit and vegetables | C10.3 | 01.1.6 | Fruits and nuts | 01 |
| | | | 01.1.7 | Vegetables, tubers, plantains, cooking bananas and pulses | 01 |
| C10 | Manufacture of vegetable and animal oils and fats | C10.4 | 01.1.5 | Oils and fats | 01 |
| C10 | Manufacture of dairy products | C10.5 | 01.1.4 | Milk, other dairy products and eggs | 01 |
| C10 | Manufacture of bakery and farinaceous products | C10.7 | 01.1.1.3 | Bread and bakery products | 01 |
| C10 | Manufacture of other food products | C10.8 | 01.1.9 | Ready-made food and other food products n.e.c. | 01 |
| C11 | **Manufacture of beverages** | **C11** | **mixed** | | |
| C11 | Manufacture of beverages | C11.0 | 02.1 | Alcoholic beverages | 02 |
| | | | 01.2 | Non-alcoholic beverages | 01 |
| C12 | **Manufacture of tobacco products** | **C12** | **02.3** | **Tobacco** | 02 |
| C13 | **Manufacture of textiles** | **C13** | **05.2** | **Household textiles** | 05 |
| C14 | **Manufacture of wearing apparel** | **C14** | **03.1** | **Clothing** | 03 |

| NACE division | NACE/WZ English | NACE class | COICOP class | COICOP English | COICOP division |
|---|---|---|---|---|---|
| C15 | **Manufacture of leather and related products** | **C15** | mixed | | |
| C15 | Tanning and dressing of leather; manufacture of luggage, handbags, saddlery and harness; dressing and dyeing of fur | C15.12 | 13.2.9 | Other personal effects | 13 |
| C15 | Manufacture of footwear | C15.20 | 03.2 | Footwear | 03 |
| C17 | **Manufacture of paper and paper products** | **C17** | **09.7.4.** | **Stationary and drawing materials** | 09 |
| C18 | **Printing and reproduction of recorded media** | **C18** | **09.7** | **Newspapers, books and stationary** | 09 |
| C19 | **Manufacture of coke and refined petroleum products** | **C19** | mixed | | |
| C19 | Manufacture of coke oven products | C19.1 | 04.5.4 | Solid fuels | 04 |
| C19 | Manufacture of refined petroleum products | C19.2 | 07.2.2 | Fuels and lubricants for personal transport equipment | 04 |
| C20 | **Manufacture of chemicals and chemical products** | **C20** | **05.6** | **Goods and services for routine household maintenance** | 05 |
| C21 | **Manufacture of basic pharmaceutical products and pharmaceutical preparations** | **C21** | **06.1** | **Medical products, appliances and equipment** | 06 |
| C22 | **Manufacture of rubber and plastic products** | **C22** | mixed | | |
| C22 | Manufacture of rubber products | C22.1 | 07.2.1.1. | Tyres | |
| C22 | Manufacture of plastic products | C22.2 | 05.6.1 | Non-durable household goods | 05 |
| C23 | **Manufacture of other non-metallic mineral products** | **C23** | **05.4** | **Glassware, tableware and household utensils** | 05 |
| **C23** | **Manufacture of glass and glass products** | **C23.13** | **05.4** | **Glassware, tableware and household utensils** | **05** |
| C25 | **Manufacture of fabricated metal products, except machinery and equipment** | **C25** | mixed | | |
| C25 | Manufacture of cutlery, tools and general hardware | C25.71 | 0.5.4.0.2 | Cutlery, flatware and silverware | 05 |
| C25 | Manufacture of other fabricated metal products | C25.99 | 05.5.2.2 | Miscellaneous accessories | 5 |

(Fortsetzung)

| NACE division | NACE/WZ English | NACE class | COICOP class | COICOP English | COICOP division |
|---|---|---|---|---|---|
| C26 | **Manufacture of computer, electronic and optical pro! ducts** | **C26** | mixed | | |
| C26 | Manufacture of computers and peripheral equipment | C26.2 | 08.1 | Information processing equipment | 09 |
| C26 | Manufacture of communication equipment | C26.3 | 08.1 | Information processing equipment | 09 |
| C26 | Manufacture of consumer electronics | C26.4 | 08.1.4 | Equipment for the reception, recording and reproduction of sound and vision | 08 |
| C26 | Manufacture of instruments and appliances for measu-ring, testing and navigation; watches and clocks | C26.5 | 13.2.1 | Jewellery and watches | |
| C26 | Manufacture of irradiation, electromedical and electrothe-rapeutic equipment | C26.6 | 06.1.3 | Assistive products | 06 |
| C26 | Manufacture of optical instruments and photographic equipment | C26.7 | 09.1.1 | Photographic and cinematographic equipment and optical instruments | 09 |
| C26 | Manufacture of magnetic and optical media | C26.8 | 08.1.5 | Unrecorded recording media | 08 |
| C27 | **Manufacture of electrical equipment** | **C27** | mixed | | |
| C27 | Manufacture of electric lighting equipment | C27.4 | 05.1.1.3 | Lighting equipment | 05 |
| C27 | Manufacture of domestic appliances | C27.5 | 05.3 | Household appliances | 05 |
| C28 | **Manufacture of machinery and equipment n.e.c.** | **C28** | mixed | | |
| C28 | Manufacture of general-purpose machinery | C28.1 | 09.2.1.3 | Boats, yachts, outboard motors and other watersport equipment | 09 |
| C28 | Manufacture of other general-purpose machinery | C28.2 | 05.5.2.1 | Non-motorized tools | 05 |
| C28 | Manufacture of agricultural and forestry machinery | C28.3 | 05.5.1 | Motorized tools | 05 |
| C29 | **Manufacture of motor vehicles, trailers and semi-trai-lers** | **C29** | mixed | | |
| C29 | Manufacture of motor vehicles, trailers and semi-trailers | C29.1 | 07.1 | Purchase of vehicles | 07 |
| C29 | Manufacture of parts and accessories for motor vehicles | C29.3 | 07.2 | Operation of personal transport equipment | 07 |
| C30 | **Manufacture of other transport equipment** | **C30** | **07.1** | **Purchase of vehicles** | 07 |
| C31 | **Manufacture of furniture** | **C31** | **05.1** | **Furniture, furnishings, and loose carpets** | 05 |

| NACE division | NACE/WZ English | NACE class | COICOP class | COICOP English | COICOP division |
|---|---|---|---|---|---|
| C32 | **Other manufacturing** | **C32** | mixed | | |
| C32 | Manufacture of jewellery, bijouterie and related articles | C32.1 | 13.2.1 | Jewellery and watches | 13 |
| C32 | Manufacture of musical instruments | C32.2 | 09.5.1 | Musical instruments | 09 |
| C32 | Manufacture of sports goods | C32.3 | 09.2.2 | Equipment for sports | 09 |
| C32 | Manufacture of games and toys | C32.4 | 09.2.1 | Games, toys and hobby goods | 09 |
| C32 | Manufacture of medical and dental instruments and supplies | D32.5 | 06.1.3 | Assistive products | 06 |
| C32 | Manufacturing n.e.c. | C32.99 | 13.2 | Other personal effects | 13 |
| C33 | **Repair and installation of machinery and equipment** | **C33** | mixed | | |
| C33 | Repair and installation of machinery and equipment | C33.1 | 06.1.4 | Repair of therapeutic appliances and equipment | 06 |
| C33 | Repair of electronic and optical equipment | C3313 | 08.3.5 | Repair and rental of information and communication equipment | 08 |
| D35 | **Electricity, gas, steam and air conditioning supply** | **D35.1** | **04** | **Housing, water, electricity, gas and other fuels** | 04 |
| D35 | Electric power generation, transmission and distribution | D35.1 | 04.5.1 | Electricity | 04 |
| D35 | Manufacture of gas; distribution of gaseous fuels through mains | D35.2 | 04.5.2 | Gas, including share in the costs | 04 |
| D35 | Steam and air conditioning supply | D35.3 | 045.5.2.1 | District heating and others | 04 |
| E36 | **Water collection, treatment and supply** | **E36** | **04.4.1** | **Water supply** | 04 |
| E37 | **Sewerage** | **E37** | **0443** | **Sewage disposal** | 04 |
| E38 | **Waste collection, treatment and disposal activities; materials recovery** | **E38** | **0442** | **Refuse collection** | 04 |
| G45 | **Wholesale and retail trade and repair of motor vehicles and motorcycles** | **G45** | **07.2.3** | **Maintenance and repair of personal transport equipment** | 07 |
| G45 | Maintenance and repair of motor vehicles | G45.2 | 07.2.3 | Maintenance and repair of personal transport equipment | 07 |

(Fortsetzung)

| NACE division | NACE/WZ English | NACE class | COICOP class | COICOP English | COICOP division |
|---|---|---|---|---|---|
| S95 | **Repair of computers and personal and household goods** | **S95** | mixed | | |
| S95 | **Repair of personal and household goods** | **S95.2** | mixed | | |
| S95 | Repair of consumer electronics | **S9521** | **09.4.1** | Hire and repair of photographic and cinematographic equipment and optical instruments | 09 |
| S95 | Repair of household appliances and home and garden equipment | **S9522** | **13.1.1.2** | Repair of electric appliances for personal care | 13 |
| S95 | Repair of household appliances and home and garden equipment | **S9522** | **09.4.2** | Hire, maintenance and repair of major durables for recreation | 09 |
| S95 | Repair of footwear and leather goods | **S9523** | **03.2.2** | Cleaning, repair, and hire of footwear | 03 |
| S95 | Repair of furniture and home furnishings | **S9524** | **04.3.1.1** | Materials for the maintenance and repair of the dwelling | 04 |
| S95 | Repair of furniture and home furnishings | **S9524** | **05.1.2** | Repair, installation and hire of furniture, furnishings and loose carpets | 05 |
| S95 | Repair of watches, clocks and jewellery | **S9525** | **13.2.1.2** | Repair and hire of jewellery, clocks and watches | 13 |
| S95 | Repair of other personal and household goods | **S9529** | **09.4.4** | Hire and repair of equipment for sport, camping and open-air recreation | 09 |
| S95 | Repair of other personal and household goods | **S9529** | **13.2.9.2** | Repair or hire of other personal effects n.e.c | 13 |

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# 10 Intellectual Property Rights in a Fab City/ Open-Source Hardware Context

## Between Obstacle and Necessity

Dana Beldiman, Fabian Flüchter and Felix Tann

> *"In real open source, you have the right to control your own destiny."*
>
> *Linus Torvalds*

## 10.1 Introduction

The term "Fab City" describes a city that is both "globally connected" and "locally productive" (Fab City Global Initiative, n.d.). It envisions "cities and regions" that "share data, information and know-how […], whereas the creation, repair and recycling of those physical goods and artifacts happens in the local sphere close to the place of need" (Interfacer, 2022, p. 4; see no. 9: Fab City Global Initiative, 2018). The concept of sharing, deeply ingrained in open-source philosophy, is further associated with communal ownership over data and technology in a digital space such as a "Digital Commons" (Bauwens et al., 2019, p. 7).

To create this open ecosystem, which may help establish a circular economy, a Fab City requires, besides a digital, also a legal infrastructure, i.e., rules governing the exchange of data and knowledge, which are essential to "control your own destiny", as aptly put by

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M. Moritz et al. (Hrsg.), *Global collaboration, local production*, SDG – Forschung, Konzepte, Lösungsansätze zur Nachhaltigkeit,
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Linus Torvalds, the creator of the Linux Kernel.[1] The law presents two conflicting approaches to the sharing of "data, information and know-how". One of these approaches is based on intellectual property rights ("IPRs") and protects the product of intellectual work, such as creations, inventions, symbols, designs, and secret information (WTO, n.d.). IPRs create exclusivity in their respective owners and entitle them to prevent the unauthorized use of protected property by third parties.

The other approach, by contrast, is based on the credo of the open-source movement and requires knowledge to be shared and made available, free from exclusive rights (Ackermann, 2009, p. 183). This movement first took hold in the field of software development. Consistent with this credo, both the open-source software ("OSS") and the open-source hardware ("OSH") movements embody the concept of freedom to study, use, modify, and distribute software (Stallman, 1986, p. 8).

Against this backdrop, scholars (Thiruthy, 2017 pp. 80–81) have questioned whether open-source (OS) and IPR are modes of knowledge governance which can coexist. Closer examination shows that, while seemingly in tension, OS and IPR constitute symbiotic modes of knowledge production and dissemination, both based on IPR. While IPRs are designed to incentivize innovation by means of exclusivity, they also enable the existence of OS. In this way, use of IPRs plays a crucial role in the Fab City context: on the one hand, to ensure openness, and on the other, to generate value. We will address this seeming dichotomy in this article. We will further examine the relevance of IPRs and their respective features to the Fab City framework and address licensing challenges that may emerge from their use.

## 10.2 Creating Openness Using IPRs

OSS first emerged over two decades ago, with the four freedoms – to run, copy, distribute, study, change, and improve software – articulated by Richard Stallman (1986, p. 2). Today it is clear that OSS has brought about a paradigm shift in the production and dissemination of knowledge. More than 35 million developers contribute to code (Agarwal, 2021), 90% of companies use OSS (Octoverse, 2022), and major companies, who use a proprietary business model, such as Microsoft, use and invest into OSS.

The reasons for the rapid growth of OSS are numerous. First, and most obvious, is the fact that OSS is generally free to use and distribute. Second, OSS provides flexibility. It is easily modifiable and customizable to meet users' specific needs (Daley et al., 2018, p. 10). Next, OSS fosters collaboration. Most software projects are developed collaboratively by a community of developers and result in follow-on innovation, faster development cycles, and higher quality. Users also consider OSS more secure. Vulnerabilities can be identified and fixed rapidly, given the publicly available source code that can be audited

[1] The Linux Kernel is one of the most important pieces of open-source software in terms of popularity and distribution (Truelist, 2023).

by the community (Beldiman, 2018, pp. 27–28). Finally, the key benefit of OSS is its openness. Almost counterintuitively, openness is achieved as an effect of IPRs. It is commonly accepted that IPRs operate by granting owners exclusive rights in their inventions or creations. However, on the flipside, IPRs can effectively create openness as well. The existence of an exclusive IP right allows its holder to impose conditions on the transfer of its IP to third parties. An IP owner who conditions transfer of source code or modifications thereto, on their continued downstream openness has established an open license (Nadan, 2002, p. 357), which grants users free access to utilize, modify, and distribute the source code and its derivatives. In this manner, a symbiotic interplay occurs between IPRs and open-source. IPRs can operate on the one hand, to create exclusivity and incentivize innovation; on the other, they establish the conditions underlying openness. This duality provides members of the Fab City ecosystem with flexibility in structuring its flow of knowledge and opportunities to create value based upon it.

The "open" philosophy embodied in OSS was readily adopted by the OSH system. From an intellectual property perspective, creating OSH is analogous to creating OSS. Exclusive IPRs to OSH components can be used to enable users to freely access, use, modify, and distribute them. The key difference, however, is that, unlike OSS which involves digital bits, OSH deals with tangible atoms (Beldiman, 2018, p. 29). With tangible, physical objects, come costs. Unlike software, the production of hardware products requires up-front expenses in purchasing raw materials, production equipment, transportation, storage, etc.

Thus, unlike OSS, where the costs associated with developing code are fairly balanced by an incentive structure based on subjective intrinsic and extrinsic motivations (Boudreau & Lakhani, 2015, p. 8), the OSH inventor also faces a possibly significant outlay of cash in the course of the development process. Without the prospect of the ultimate reward provided by the IP system, production of OSH poses economic challenges to the small inventor.

A further impact of tangibility is that, compared to an OSS context, different IP laws may apply to OSH. While the OSS system relies exclusively on copyright, which arises automatically upon a work's creation, OSH may involve patents, designs and utility models, to which rights must first be acquired, before being able to construct a free sharing environment.

That said, the Fab City ecosystem relies heavily on the open system which enables a free exchange of information within a global network of cities. Utilizing OSS and OSH licenses, this ecosystem can achieve a process whereby intangible "bits", including data, code, designs and documentation, created anywhere in the world, can reach remote local production sites where they are converted into tangible products (atoms). Without an underlying framework of OSS, such a network would be nearly impossible to establish.

### 10.2.1 The Relevance of IPRs for Open Value Creation

As described above, OSH projects involve sharing code, designs and technical information with the wider community, as well as the production of physical goods. All these instantiations of the OSH process are governed by IPRs, whether patents, utility models, design rights, copyright, trade secrets, or trademarks. Understanding how IPRs may be involved in the OSH process, their legal implications, as well as the requirements for obtaining rights, will facilitate collaborative and open initiatives on the one hand, and protection of intellectual assets on the other. The following will examine the IPRs that may be implicated in OSH processes.

#### 10.2.1.1 Patents

Patent law protects functional utilitarian inventions as products and as processes (methods). The patent owner is granted the right to prevent others from making, using, selling, offering for sale and importing the patented invention (Article 28 TRIPS Agreement). Patent rights are territorial, in other words, they are valid and enforceable only in the country where the patent is registered (e.g., German patent rights are limited to Germany, while US patent rights to the United States). The validity of a patent is typically limited to 20 years (Article 33 TRIPS Agreement).

Patents have been crucial in protecting the early basic 3D printing technologies, such as fused deposition modeling (FDM), stereolithography (SLA), and selective laser sintering (SLS).[2] The expiry of all three patents enabled the creation of community-driven projects such as RepRap[3] and Thingiverse,[4] which helped foster a global community of OSH developers and enthusiasts. These projects have encouraged collaboration and innovation, leading to the development of new technologies and products, having the potential to transform entire industries.

Eligibility for patents is based on four core criteria (Article 27 §§ 1–3 TRIPS Agreement). The invention

- (1) must consist of patentable subject matter, i.e., the invention must be functional, not purely aesthetic, and not related to certain excluded categories, such as human genes or animal breeds, while it should also not violate public policy;
- (2) must be novel, i.e., the invention must not form part of the "state of art", which includes "everything made available to the public by means of a written or oral description, by use, or in any other way before the filing of the patent application" (Article 27 § 1 TRIPS Agreement);
- (3) must be non-obvious and therefore require an inventive step. The criterion of obviousness is meant to exclude any trivial inventions from patent protection (Article 27 § 1 TRIPS Agreement), and
- (4) must be useful and therefore have an industrial application (Article 27 § 1 TRIPS Agreement).

[2] Cf. US patent US5503785A for FDM, US patents US4575330A and US5155324A for SLA.

[3] https://reprap.org

[4] https://www.thingiverse.com

Provided a patent application is filed for an invention that fulfills all the required conditions, the competent patent office has the power to grant the patent.

Patent rights, as all other IPRs, are capable of both proprietary and open use. On the proprietary front, the inventor has the right to preclude others from using and monetizing the invention for the duration of the patent. In an OSH context, this would translate to the ability to ensure that a patented invention is not copied or misused. Conversely, when the OSH project uses third-party technology, it is essential to ascertain whether the technology is subject to a patent. Proactiveness in this regard may prevent legal repercussions that may halt the project.

Patents can also be used to maintain the openness of an invention. This would require the owner to forego enforcement of the patent against any transferees who abide by the owner's license conditions, including openness. Note that a patent registration is required for this purpose; a simple, unpatented invention, is insufficient for the creation of an open license.

#### 10.2.1.2 Utility Models

As "little cousins" of patents, most countries' laws protect utility models, which, similar to patents, protect technical products, apparatus and substances (but, unlike patents, no processes), upon showing of novelty and an inventive step. During the 10-year exclusivity period, a utility model holder has the right to prevent others from unauthorized commercial exploitation of the protected invention. Applications are generally not subject to a substantive examination and registration issues in a matter of weeks.

Several aspects make utility models extremely attractive in OSH contexts. First, they are inexpensive and easy to obtain. A utility model is a good substitute, for purposes of both proprietary and open use, when obtaining patent protection is impossible, due to cost, time or a low level of inventiveness. The openness of an OSH license can be based on a utility model registration. Second, utility models constitute prior art for purposes of patent applications, a feature useful to OSH inventors who seek to maintain a given field of technology in the public domain. Finally, utility models offer a 6-month grace period (in other words, their owner may use them for up to 6 months prior to filing of the application, without their novelty being destroyed). This fact makes them popular in instances where the invention is already in use.

#### 10.2.1.3 Copyright

Copyright law provides protection for a variety of creative works including all types of writings, music, painting, sculpture, cinematographic works, dance, software code and possibly specific patterns of circuit boards (Article 2 § 1 Berne Convention). The scope of copyright is defined by the national law of each country but generally grants authors the exclusive economic rights to reproduce, modify and distribute copyrighted works.

Because rights arise upon creation of the works, once they are fixed in a tangible means of expression (Article 2 § 2 Berne Convention), no formalities, such as applications or registrations are required.[5] Furthermore, the required threshold of creativity is quite low, with the result that most works are considered protectable. This means that virtually all programmers automatically are deemed to be owners of copyright in the software they develop.

Copyright is essential to the Fab City ecosystem as its features lend themselves best for creating openness by way of the OSS license, as well as, to some extent, the OSH license. Copyright applies to all types of digital "writings", including software code, designs, and technical documentation. In the OSH context, software is, for instance, used to control RepRap 3D printers (firmware and graphical user interface). The software code itself is subject to copyright as is the applicable technical documentation, such as design files needed to build and modify hardware (for reference and documentation: Duet3D, n.d.).

To qualify for copyright protection, a work is required to be a personal intellectual creation and must

- (1) be the result of human creation, i.e., machines cannot create copyrightable works (Ginsburg, 2018, pp. 133–134);
- (2) be in a form that is perceivable to humans (Ricketson & Ginsburg, 2006, p. 403 (8.03), 499 (8.105));
- (3) be influenced by the creator's spirit, i.e., tedious mechanical work that is performed without thinking would not qualify for protection (Justitia, 1991); and
- (4) meet a minimum standard of creative quality, i.e., the answers given while filling out a governmental form would not qualify as a copyrightable work, as they are solely dependent on the circumstances (Ricketson & Ginsburg, 2006, p. 402 (8.03), 405(8.05)).

As with other IP rights, copyright can be applied in a proprietary as well as in an open manner. The former entails the exclusionary exercise of the rights to copy, modify and distribute with the goal that the author's retain control over the work. Use of copyright under an "open" philosophy manifest in the OSS license which frees up access and use of the copyrighted work.

#### 10.2.1.4 Trade Secrets

Trade secret laws protect valuable and classified information that is kept secret. It does not protect against a third party's independent discovery of the secret information. In other words, if a third party independently and without malice discovers the secret information it is allowed to use it without incurring liability. Usually, the trade secret is destroyed as a result, as the "cat is out of the bag". As with copyright, trade secret protection arises automatically (registration is not required). Protection lasts for an indefinite amount of time, or as long as the trade secret remains classified.

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[5] Although in some countries such as the US registration might benefit enforcement of copyright.

In principle, any information qualifies for trade secret protection, if it

- (1) is secret in the sense that it is not commonly known (Article 39 § 2 lit a TRIPS Agreement);
- (2) has commercial value because it is secret (Article 39 § 2 lit b TRIPS Agreement); and
- (3) is subject to reasonable steps to keep it secret (Article 39 § 2 lit c TRIPS Agreement).

Trade secret protection allows its owner to prohibit others from disclosing and misappropriating secret information, if obtained through illegal means (e.g., through corporate espionage via hacking a server; Article 39 § 2 TRIPS Agreement). Trade secrets may provide the requisite secrecy for items which are to be ultimately protected by patents, designs, trademarks, etc., and help in preparing applications for such rights without fear of interference by malicious third parties. Once the project is released to the public or the right is granted and published, trade secret protection terminates automatically.

#### 10.2.1.5 Design Rights

Design rights protect aesthetic features of products. They provide the owner with exclusive rights to prohibit others from using identical or similar designs and, in most countries, come in a registered and unregistered version. Registration is usually required to obtain protection and the rights are limited to the territory in which they are registered. Registered design rights usually last for 10 years with options to extend the registration period, while this timeframe is often shorter for unregistered design rights (e.g., 3 years for an unregistered EU design right).

For example, Apple Inc. possesses design rights for the distinctive appearance of its iPhone models.[6] Design rights may also be used for protecting the visual appearance of a graphic user interface. In the context of OSH, design rights could be applied to e.g., the visual appearance of hardware components or the stylization of accompanying software.

Designs may be protected if they are new and have an individual character (Article 3 § 2 EU Directive on the Legal Protection of Designs). These requirements entail that the overall impression of a design be significantly different from existing ones (Articles 4 and 5 § 1 EU Directive on the Legal Protection of Designs). If the design's features are mostly dictated by technical or functional characteristics, they are excluded from being eligible for protection (Article 7 § 1 EU Directive on the Legal Protection of Designs).

Securing design rights enables companies to prohibit competitors from creating or selling products that look identical or similar. For OSH developers, obtaining design rights can ensure that their hardware designs remain unique and distinguishable from those of competitors, while also providing the opportunity to license the designs on reasonable and equitable terms to others, ultimately helping to promote innovation and collaboration within the OSH community while also safeguarding the integrity of the design.

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[6] Cf. e.g., EU-registered community design 002421701-0015.

#### 10.2.1.6 Trademarks

Trademark law protects symbols that distinguish products or services of one entity from those of another. They grant the exclusive right to use the registered trademark and prohibit third parties from using identical or similar trademarks that could cause confusion among consumers. In most countries, registration is a prerequisite for trademark protection, and the associated rights are restricted to the jurisdiction where they are registered. Once granted, trademarks are usually valid for 10 years. However, if in continuous use, they can be renewed without limitation.

Certification marks represent a specific use case of trademarks, indicating that products or services meet certain quality, safety or environmental standards established by an independent organization. For instance, the "OSHWA certification mark" is awarded by the Open-Source Hardware Association to hardware products that meet specific criteria relating to openness, documentation, and licensing (OSHW, n.d.).

The requirements for trademark registration are as follows: first, a sign needs to be capable of distinguishing the owner's intended products from those of competitors (Article 15 § 1 TRIPS Agreement). The sign should not be understood to describe the properties of the intended product but should act as an indicator of the product's origin. Second, the sign should not be confusingly similar to prior registered trademarks (Article 16 § 1 TRIPS Agreement).

In OSH projects, trademarks may primarily serve to safeguard the branding elements. While they may not prevent third parties from copying a product's features, trademarks can help maintain quality consistency.

#### 10.2.1.7 Summary of Relevant IPRs

It follows from the analysis above that several IPRs may be involved in the OSH process in different ways. These rights and the parts of OSH they may be attached to are broadly summarized in Table 10.1.

**Table 10.1** IPRs and their relevance for OSH

| Type of intellectual property right | Relevant part of OSH |
|---|---|
| Patents | Technical products, apparatus, and substances |
| Utility models | Technical products, apparatus, and substances |
| Copyright | Creative works including all types of writings, music, painting, sculpture, cinematographic works, dance, software code and possibly specific patterns of circuit boards |
| Trade secrets | Any classified information that is kept secret |
| Design rights | Aesthetic features of products |
| Trademarks | Branding |

## 10.3 Challenges to Licensing IPRs in the Fab City

We believe that open licenses, specifically licenses which grant permission to access, use, modify, and distribute a work freely, subject to limited and non-monetary restrictions, are crucial in facilitating access to knowledge by allowing the sharing of ideas and intellectual property rights through contractual agreements. It should be kept in mind, however, that the options for OSS are as diverse as the open-source material that is licensed. When choosing the appropriate open license, it is therefore important to consider the OSH project's licensing needs for software as well as for hardware.

As explained above, open licenses may be used to control the flow of knowledge. Their openness is primarily premised on two provisions: the first results directly from the primary function of a license, which is the permission to use, modify and distribute the licensed content; the second is to require that any further re-distribution of the licensed material, or derivatives thereof, must adhere to the same conditions (Nadan, 2002, p. 357). This is also known as the "viral" effect of open licenses (Gal, 2012, p. 505) and is designed to promote open sharing and accessibility to downstream users.

Today, a number of established open-source licenses exist, most of which are OSS licenses. By contrast, licenses specifically designed for OSH environments are relatively new and have not been tested in court yet. Bearing in mind that hardware and software are different in nature, not all the current licenses may be suitable to be used in a Fab City ecosystem. Against this backdrop, we examine potential issues presented by OSS and OSH licenses and discuss licensing needs within the Fab City.

### 10.3.1 Common Open Source Licenses

According to the OpenNEXT library of Open-Source Hardware, the CC-BY-SA, GPL 3.0 and CERN 1.2 licenses are among the most popular licenses used for making available OSH (OpenNEXT, n.d.). We will therefore focus on the analysis of these licenses.

#### 10.3.1.1 Creative Commons (CC) Licenses

CC licenses are designed primarily for creative works such as art, music, and other types of creative content. CC licenses are a set of standardized licenses that allow content creators to grant specific permissions in regards to how their work can be used, modified, and shared. The CC licenses include several options for different levels of permission, such as whether commercial use is allowed, whether derivative works are allowed, and whether attribution is required (an overview over CC licenses: Creative Commons, n.d.).

While these licenses can be used for OSS as well as OSH, they may not be the best choice for the latter since they are tailored towards creations such as graphic designs (Creative Commons, n.d.) and do not provide specific provisions for patents or hardware-related issues.

#### 10.3.1.2 The General Public License (GPL)

The GPL is primarily intended for open licensing of software. It ensures that any modifications or improvements made to the software are also available to the public and can be freely used and distributed. The GNU General Public License, Version 3 (GPL 3.0; GNU, 2007) which includes a copyleft feature, specifically, requiring that the work be further distributed subject to the same license as the original one, is probably one of the most frequently used licenses for making available OSS.

According to the Free Software Foundation, GPL may also be utilized for licensing physical objects such as designs of protected circuits (GNU, n.d.). Despite this recommendation, GPL 3.0 may not suit the needs of OSH-licensing, as it does not distinguish between hardware and corresponding documentation on how to build it. However, different parts of OSH, may have different licensing needs regarding the production costs associated with OSH. For instance, in some cases, while distribution of documentation (bits) must be non-commercial, this feature is not required for the distribution of assembled OSH (atoms). In addition, the license grant in the GPL depends on copyright. Although corresponding patents may also be licensed under the GPL, other rights such as designs, and utility models are not covered by the license. Finally, the wording of the license is clearly targeted towards licensing software and may create ambiguities when applied to hardware (e. g. "Source Code", "Program", "System Library", etc.).

#### 10.3.1.3 CERN 1.2 License

CERN OHL 1.2[7] is a popular open-hardware license developed by the European Organization for Nuclear Research (CERN) specifically with hardware designs in mind. In contrast to many other open licenses, it provides provisions for patents and other hardware-related issues (Ayass & Serrano, 2012, p. 72). This license is applicable to the use and distribution of documentation, as well as the manufacture and distribution of physical products.

The CERN 1.2 license is one of the first licenses to distinguish between hardware and corresponding documentation. Thus, CERN OHL 1.2 specifically provides a patent and design license. It can therefore be used on a piece of OSH containing patented or design protected hardware. The CERN 1.2 license is not a complete solution for open-source licensing. Utility models, for instance, are not covered by CERN 1.2, as they are not part of the license grant. Even more importantly, CERN 1.2 is probably not well suited for licensing software. Indeed, Sect. 2.3 of the license clarifies that the license only is applicable to software, firmware, or code as part of hardware, if it is explicitly made available under the license. The license requires the licensor to specify its application to software. Yet, when licensing software alone, necessary documentation that the license mandates be provided to any recipient of the licensed material is usually absent.

[7] The latest version of the license can be obtained from the Open Hardware Repository: OHWR, 2013.

**Table 10.2** Overview of analyzed licenses in this article

| Type of license | Where they apply |
|---|---|
| Creative Commons | Creative works (copyright) |
| General Public License | Software (copyright) |
| CERN 1.2 | Hardware and documentation (copyright, patents, design rights) |

### 10.3.2 Licensing Needs in the Fab City Eco System

As is clear from the above, today's open licenses do not address every possible licensing scenario in a single license. An overview over the licenses analyzed in this article can be found below in Table 10.2. Open licenses do not permit sharing of ideas as well as profits from open-source product sales. However, this may be necessary to address the cost reimbursement for hardware development and manufacturing. Another issue may arise in the form of license compatibility (Katz, 2012, p. 52). Since there is no one-for-all solution to the open licensing of IPRs, different licenses may need to be combined. License compatibility matters when an open license is altered to suit a modified version of the open-source material. The original license must permit the use of subsequently used open license, and the re-distribution requirements of all licenses involved must be met. As of now, with OSH, it is unclear which licenses are compatible with each other.

## 10.4 Summary and Avenues of Further Research

The above analysis shows that intellectual property cannot only coexist with an open-source philosophy, but rather that IPRs are an important pillar of the Fab City ecosystem. At first glance, intellectual property may seem to contradict the open sharing of ideas and knowledge advocated by OSS and OSH, as it appears to be centered around exclusivity. However, a closer examination reveals that IPRs can serve as valuable instruments for regulating the dissemination of knowledge, without being biased towards any particular philosophy. In fact, they can help facilitate the construction of a network of interconnected Fab Cities on a global scale. IPRs are vital to OSS as well as to OSH, because they define the legal framework for the creation, distribution, and use of both soft- and hardware (for open-source software: Mann, 2006, p. 46).

To determine how best to balance exclusivity and openness in a way that facilitates the optimal flow of knowledge in a Fab City setting, additional exploration is required to establish the specific boundaries of each system, as well as any areas of congruity between them, to maximize the benefits both systems can offer to OSH ecosystems.

So far, little general and hardly any theoretical research has been conducted relating to the intersection of intellectual property rights and OSH. Yet, this field constitutes a fertile and promising area of inquiry that would help reduce the existing legal uncertainty and identify strategies that would be helpful in problem areas which impede the flow of knowledge, such as lockouts and hold-ups.

Areas of needed research also lie in the arena of open-source licensing. Sharing knowledge under IPRs can create value in the OSH context by allowing others to build and improve on existing knowledge. From a legal and business standpoint, the most secure way to do this is probably by means of open-source licenses. Yet, although various open licenses are available, none of them fully address the specific licensing needs of a Fab City network. In addition, compatibility issues may severely hinder the use of open licenses and with it the free distribution of knowledge.

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# Haftungsrisiken im Kontext von Open Source Hardware

# 11

Linda Kuschel und Lisa Haller

*„Der Mut zu vertretbaren Risiken kann verändern helfen"*

*Dieter Gropp*

## 11.1 Einleitung

Die Fab City Bewegung steht für ein innovatives urbanes Konzept, das ganz wesentlich durch Open Source Hardware (OSH) als offene, progressive Produktionsmethode, geprägt ist. OSH hat das Potential, sich positiv auf die Gesellschaft auszuwirken und kann einen wichtigen Beitrag für mehr Nachhaltigkeit leisten, etwa durch den effizienteren Einsatz von Ressourcen und das Einsparen von Transport- und Lieferwegen (siehe Nr. 5: Fab City Hamburg; Stengel 2016, S. 78). Anders als Open Source Software (OSS) wird OSH bislang kaum aus juristischer Perspektive diskutiert.[1] Sowohl OSH als auch die Fab City, insbesondere die Zu-

[1] Juristische Beiträge zu Open Source Hardware stammen etwa von *Huppertz*, Open Source Hardware – ein erster Überblick, CR 2012, 697; *Wübbelmann*, Open Source Hardware, 2014, in Taeger, Big Data & Co – Neue Herausforderungen für das Informationsrecht; Leupold/Wiebe/*Glossner*, IT-Recht, 4. Aufl. 2021, Rn. 40–45; kurz angesprochen in *Grosskopf*, 3D Druck – Personal Manufacturing, CR 2012, 618 (624).

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M. Moritz et al. (Hrsg.), *Global collaboration, local production*, SDG – Forschung, Konzepte, Lösungsansätze zur Nachhaltigkeit,
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sammenarbeit in Fab Labs, werfen neue und anspruchsvolle rechtliche Fragen auf. Dabei erscheint es besonders wichtig, rechtliche Haftungsrisiken aufzuzeigen und dadurch transparent zu machen, wo Vorsicht bei der Entwicklung, Herstellung und Nutzung von OSH geboten ist und wie Haftungsrisiken möglichst reduziert werden können. Ziel sollte sein, zu verhindern, dass die Angst vor einer potenziellen Haftung zu unerwünschten „chilling effects" führt. Aus rechtswissenschaftlicher Perspektive besonders interessant ist, auszuloten, inwieweit das (Haftungs-) Recht Aspekte wie Altruismus und Nachhaltigkeit berücksichtigt.

Im folgenden Kurzbeitrag werden zunächst die einzelnen Akteure genannt, die am OSH-Produktionsprozess beteiligt und potenziell Haftungsrisiken ausgesetzt sind (Abschn. 11.2). Es wird dann am Beispiel des Designers aufgezeigt, wie und warum vertragliche Leistungsbeziehungen von reinen Gefälligkeiten o. ä. abzugrenzen sind (Abschn. 11.3) und die verschiedenen Haftungsrisiken des Designers kursorisch aufgezeigt (Abschn. 11.4). Der Beitrag schließt mit einem Ausblick auf einige interessante rechtliche Forschungsfragen im Kontext der Haftung für OSH (Abschn. 11.5).

Der Beitrag beschränkt sich auf Ausführungen zum deutschen Recht. Bezüglich des Produkthaftungsgesetzes (ProdHaftG) sei aber darauf hingewiesen, dass dieses Gesetz die europäische Produkthaftungsrichtlinie umsetzt und daher europaweit im Wesentlichen einheitliche Anforderungen gelten.

## 11.2 Akteure

### 11.2.1 Typische Akteure in der OSH-Wertschöpfungskette

Die Vielzahl an unterschiedlichen Akteuren, die bei OSH-Projekten agieren, und der aufgeteilte Produktionsablauf stellen das (Haftungs-)Recht vor gewisse Herausforderungen. Während klassischerweise ein Unternehmen, das ein Produkt in den Verkehr bringt, dieses auch konzipiert und herstellt, können bei OSH-Projekten eine Vielzahl nicht miteinander verbundener Personen am Produktionsprozess beteiligt sein.

Bereits in der Definition von OSH der Open Source Hardware Association (OSHWA) wird Bezug genommen auf die typischen Akteure der OSH-Wertschöpfungskette. Nach der OSHWA bezeichnet OSH „Hardware, deren Baupläne öffentlich zugänglich gemacht wurden, sodass alle sie studieren, verändern, weiterverbreiten, sowie darauf basierende Hardware herstellen und verkaufen können" (siehe Nr. 11: Open Source Hardware Grundsatzerklärung 1.0; siehe Nr. 3: DIN SPEC 3105 Open Source Hardware).

Aus dieser Definition ergibt sich, dass im OSH-Kontext ein Designer die Baupläne der Hardware (OSH-Bauplan) erstellt und öffentlich zugänglich macht, und zwar in einer Weise, die es anderen ermöglicht, diese Baupläne einzusehen, zu verändern und weiterzuentwickeln. Ein Hersteller kann sodann mithilfe des OSH-Bauplans die Hardware (OSH-Produkt) erstellen. Typischerweise veröffentlichen Designer ihre OSH-Baupläne auf einer Internetplattform, auf der sie von Herstellern gefunden und heruntergeladen werden können. Nach der Herstellung werden manche OSH-Produkte vom Hersteller selbst genutzt, andere werden an Dritte (Nutzer) veräußert. Die Herstellung des OSH-Produkts erfolgt oft in offenen Werkstätten, wie etwa in einem FabLab. In diesen offenen Werkstätten arbeiten wiederum Personen, die andere bei der Herstellung von OSH-Produkten unterstützen, etwa Instrukteure oder Workshop-Leiter.

Aus rechtlicher Perspektive ist es essenziell, herauszuarbeiten, welchen Akteur welche Pflichten treffen und für welche Mängel des OSH-Produkts bzw. für welche durch ein solches Produkt entstehenden Schäden er oder sie verantwortlich ist. Dabei ist auch zu berücksichtigen, dass OSH faktisch jedem erlaubt, selbst zum Produzenten zu werden – auch von solchen Erzeugnissen, die zuvor ausschließlich professionell bzw. industriell hergestellt wurden (so auch in Bezug auf 3D-Druck *Grosskopf*, CR 2012, S. 618). Jedermann kann theoretisch OSH-Baupläne erstellen sowie mithilfe heruntergeladener OSH-Baupläne neue Produkte herstellen. Das wirft die Frage auf, welche Qualität von solchen Produkten zu erwarten ist und welche Sorgfaltsmaßstäbe die verschiedenen Akteure bei der Herstellung eines OSH-Produktes zu beachten haben.

### 11.2.2 Potenzielle Geschädigte

Schäden im Zusammenhang mit OSH-Produkten treten typischerweise beim Hersteller oder Nutzer auf. Dem Hersteller kann ein Schaden entstehen, wenn er einen fehlerhaften OSH-Bauplan herunterlädt und Arbeitszeit sowie Ressourcen verwendet, um das OSH-Produkt herzustellen, obwohl dieses sich letztlich als nicht funktionstauglich erweist. Zudem ist denkbar, dass der Hersteller beim Produktionsprozess Körper- oder Sachschäden erleidet – sei es aufgrund eines fehlerhaften OSH-Bauplans, eines nicht funktionstauglichen Gerätes (etwa eines kaputten 3D-Druckers oder Laser-Cutters) oder aufgrund unzureichender Anleitung oder Überwachung bei der Arbeit mit einem solchen Gerät. Auch dem Nutzer des hergestellten OSH-Produkts können Schäden entstehen, die entweder aus einem fehlerhaften OSH-Bauplan oder aus der fehlerhaften Herstellung des OSH-Produktes resultieren. Abb. 11.1

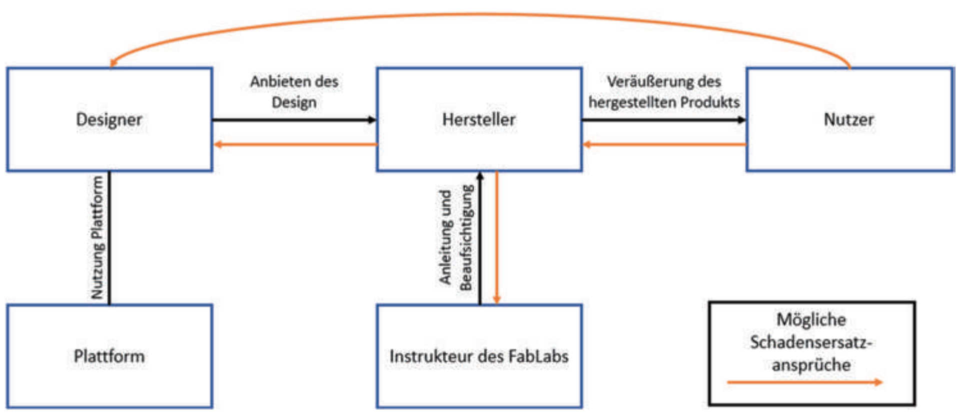


**Abb. 11.1** Abbildung der Akteure und potenzielle Schadensersatzansprüche im OSH-Kontext

Wie stets in arbeitsteiligen Produktionsprozessen, ist auch im OSH-Kontext denkbar, dass einem Akteur das Verschulden eines anderen Akteurs zuzurechnen ist – etwa ein Verschulden des Designers dem Hersteller, wenn dieser ein mangelhaftes OSH-Produkt an einen Nutzer veräußert und von dem Nutzer auf Schadensersatz in Anspruch genommen wird.

## 11.3 OSH-Design als vertragliche Leistung

Für die Abschätzung etwaiger Haftungsrisiken ist zunächst entscheidend, ob die Zurverfügungstellung des OSH-Designs eine vertraglich geschuldete Leistung des Designers darstellt. Nur wenn der Designer dem Hersteller die Bereitstellung des OSH-Designs vertraglich schuldet, kommt bei Mangelhaftigkeit des OSH-Bauplans eine Gewährleistungshaftung des Designers in Betracht. Zudem besteht nur in diesem Fall ein vertraglicher Schadensersatzanspruch. Dass zwischen dem Nutzer des OSH-Produkts und dem Designer ein Vertrag vorliegt, ist nur in Fällen denkbar in denen Designer und Hersteller personenidentisch sind. Da dies selten ist, kann in der Regel davon ausgegangen werden, dass zwischen Designer und Nutzer keine vertragliche Bindung besteht, sodass der Nutzer keine Gewährleistungsansprüche oder vertraglichen Schadensersatzansprüche gegen den Designer hat.[2]

Der Designer ist nur dann vertraglich zur Erstellung eines (fehlerfreien) Bauplans verpflichtet, wenn ein wirksamer Vertrag vorliegt. Designer veröffentlichen die OSH-Baupläne in der Regel auf Plattformen, wie etwa *Thingiverse*, sodass ein entsprechender Vertragsschluss ggf. online zustande käme (siehe Nr. 19: Thingiverse). Der Vertragsschluss im Internet richtet sich nach den allgemeinen Regeln (Handbuch Multimedia-Recht/*Kitz* Teil 13.1 Rn. 1). Das bedeutet es müssen zwei korrespondierende Willenserklärungen vorliegen, die auf Abschluss eines entsprechenden Vertrages gerichtet sind. Es bedarf einer Auslegung, welcher Erklärungswert den Willensäußerungen der Parteien im elektronischen Geschäftsverkehr zukommt. Bei der Auslegung ist auf das Verständnis des durchschnittlichen Internetnutzers abzustellen, der mit den Besonderheiten des Internets vertraut ist (Handbuch Multimedia Recht/*Kitz* Teil 13.1 Rn. 8).

Grundsätzlich ist keine explizit auf den Vertragsabschluss gerichtete Willensäußerung erforderlich, vielmehr genügt, dass sich aus der Willensäußerung konkludent ergibt, dass das Verhalten der Partei auf den Abschluss eines Vertrages gerichtet ist. So ist etwa denkbar, dass bereits in dem Hochladen eines OSH-Bauplans auf eine Platt-

[2] Ein vertraglicher Anspruch des Nutzers gegen den Designer ist nur denkbar in Fällen, in denen der Vertrag zwischen dem Hersteller und dem Designer „Schutzwirkung" ggü. dem Nutzer entfaltet. Das setzt voraus, dass der Nutzer mit der Leistung bestimmungsgemäß in Berührung kommt. Dies muss erkennbar für den Designer sein. Das ist in der Regel nur für nahe Familienangehörige des Herstellers anzunehmen oder für dessen Angestellten.

form wie etwa *Thingiverse* ein konkludentes Angebot des Designers auf Abschluss eines entsprechenden Vertrages zu sehen ist. Dafür erforderlich ist aber, dass der Designer den OSH-Bauplan hochgeladen hat mit dem Wissen, eine rechtserhebliche Erklärung abzugeben. Wenn der Designer nicht davon ausgehen muss, dass dem Hochladen des OSH-Bauplans eine rechtsgeschäftliche Bedeutung zukommt, ist grundsätzlich mangels Rechtsbindungswillens nicht von einem Angebot auf Abschluss eines Vertrages auszugehen.

Eine auf Vertragsschluss gerichtete Erklärung muss mit Rechtsbindungswillen abgegeben werden, das bedeutet, mit dem Willen sich rechtlich binden zu wollen. Um den Rechtsbindungswillen der Parteien festzustellen, ist zu ermitteln, wie der Erklärungsempfänger die Erklärung verstehen durfte. Wenn nach der Auslegung der (konkludenten) Erklärungen von Designer und Hersteller anzunehmen ist, dass die Parteien sich nicht rechtlich binden wollen, dann ist nicht von einem Vertragsschluss auszugehen. Kriterien zur Auslegung der Erklärungen der Parteien sind zum Beispiel die Art und der Zweck der Leistung sowie die Interessenlage der Parteien. Im Kontext von OSH-Bauplänen ist relevant, welche erkennbare wirtschaftliche und rechtliche Bedeutung, der Hersteller dem Erhalt eines mangelfreien OSH-Bauplans beimisst (MüKoBGB/*Schäfer*, BGB, § 662 Rn. 25). Zu berücksichtigen sind auch die Gefahren, die von Leistungsstörungen ausgehen, sowie die Umstände, unter denen die Leistung erbracht wird (*Wendehorst*, NJW 2021, S. 2913, 2916).

Die Frage, ob die Parteien sich rechtlich binden wollen, kann nicht für alle OSH-Produkte einheitlich beantwortet werden. Bei kleineren und unbedeutenderen sowie weniger gefahrträchtigen OSH-Produkten ist grundsätzlich nicht von einer vertraglichen Bindung von Designer und Hersteller auszugehen, jedenfalls wenn der Designer dem Hersteller den OSH-Bauplan unentgeltlich zur Verfügung stellt. Wenn das OSH-Produkt ein Schlüsselanhänger oder ein Flaschenöffner ist, ist wohl eher nicht von einer vertraglichen Bindung auszugehen, denn für beide Parteien haben diese OSH-Produkte keine erkennbare wirtschaftliche oder rechtliche Bedeutung. Auch gehen von diesen Produkten keine ernstzunehmenden Gefahren aus. Anders ist die Situation zu beurteilen, wenn dem OSH-Produkt ein gewisses Gefahrenpotenzial immanent ist, wie etwa bei einem Fahrrad oder Lastenrad. Maßgeblich bei der Ermittlung, ob der Designer sich rechtlich binden will, ist wie der Hersteller eine entsprechende Erklärung des Designers verstehen muss (§§ 133, 157 BGB). Zu berücksichtigen ist, dass der Designer, nachdem er den OSH-Bauplan auf eine Plattform hochgeladen hat, keine Kontrolle mehr darüber hat, wer diesen OSH-Bauplan herunterladen und nutzen kann. Das spricht grundsätzlich gegen einen Rechtsbindungswillen. Zudem ist denkbar, dass der Designer ausdrücklich erklärt, sich nicht vertraglich binden zu wollen. In einem solchen Fall kann der Hersteller grundsätzlich nicht davon auszugehen, dass in der Zurverfügungstellung des OSH-Bauplans eine rechtlich bindende Erklärung des Designers zu sehen ist.

## 11.4 Haftungsrisiko des Designers

### 11.4.1 Verbreitungsformen und Schadensszenarien

OSH-Designer veröffentlichen ihre Baupläne typischerweise auf Internetplattformen, die es Nutzern ermöglichen, 3D-druckbare Designs zu finden, zu erstellen und zu teilen (siehe Nr. 19: Thingiverse). Ist ein OSH-Bauplan fehlerhaft, kann dies dazu führen, dass das hergestellte OSH-Produkt nicht funktionstauglich ist oder ein unsicheres OSH-Produkt entsteht und so bei der Herstellung oder der Nutzung Personen oder Sachen zu Schaden kommen.

Bei der Frage, für was der Designer einstehen muss, ist zu differenzieren zwischen der Haftung auf Ersatz des Äquivalenzinteresses Abschn. 11.4.2 und der Haftung auf Ersatz des Integritätsinteresses Abschn. 11.4.3. Während das Äquivalenzinteresse auf die Einhaltung der vertraglichen Leistungspflichten gerichtet ist, beinhaltet das Integritätsinteresse den Schutz der Rechtsgüter des Vertragspartners. Im Rahmen des Integritätsinteresse ist zu unterscheiden zwischen vertraglichen Ansprüchen, deliktischen Ansprüchen und Ansprüchen aus dem Produkthaftungsgesetz.

### 11.4.2 Haftung auf das Äquivalenzinteresse/Gewährleistungshaftung

Das Äquivalenzinteresse ist das Interesse an der Erfüllung der vertraglichen Pflichten. Voraussetzung für entsprechende Pflichten ist, dass zwischen Designer und Hersteller überhaupt ein Vertrag besteht. Davon ist bei einer unentgeltlichen Überlassung der OSH-Baupläne nicht ohne Weiteres auszugehen (siehe Abschn. 11.3).

Bei Fehlen eines Schuldverhältnisses besteht kein vertraglicher Schadensersatzanspruch des Herstellers gegen den Designer auf Ersatz des Äquivalenzinteresses. Wenn der Designer und der Hersteller allerdings ein entsprechendes Schuldverhältnis geschlossen haben und der Designer von dem Hersteller erfolgreich auf Ersatz des Äquivalenzinteresses in Anspruch genommen wird, muss der Designer den Hersteller so stellen, wie dieser bei ordnungsgemäßer Vertragserfüllung stehen würde.

**Unentgeltliche Weitergabe des OSH-Designs**
Wenn der Designer die OSH-Baupläne unentgeltlich und auch nicht gegen die „Zahlung von Daten“ (vgl. § 327 Abs. 3 BGB) anbietet, stellt sich die Frage, ob der Designer für die Mangelfreiheit seines OSH-Bauplans einstehen muss.

Das BGB sieht für die Bereiche des Kaufrechts (§§ 437 ff. BGB), des Mietrechts (§§ 536 ff. BGB), des Werkvertragsrechts (§§ 634 ff. BGB) und bei Verbraucherverträgen über digitale Produkte (§§ 327i ff. BGB) Gewährleistungsansprüche vor, das heißt, dass der Schuldner für die Mangelfreiheit der von ihm geleisteten Sache einstehen muss. All diese Verträge setzen aber eine Gegenleistung voraus – der Kaufvertrag die Zahlung eines

Kaufpreises, der Mietvertrag die Zahlung eines Mietzinses, der Werkvertrag die Zahlung einer Vergütung und der Verbrauchervertrag über digitale Produkte die Zahlung eines Preises oder von Daten. Wenn der Hersteller den OSH-Bauplan unentgeltlich herunterlädt, liegt folglich keiner der oben genannten Verträge vor. Das bedeutet, dass der Hersteller gegen den Designer keinen Anspruch auf Mängelgewährleistung hat, er also weder die Nachbesserung des OSH-Bauplans noch die Nachlieferung eines mangelfreien OSH-Bauplans verlangen kann (*Leupold/Wiebe/Glossner*, IT-Recht 2021, Teil 1 Rn. 42).

Für unentgeltliche Verträge, wie die Schenkung und die Leihe, ist im Gesetz kein Mängelgewährleistungsrecht vorgesehen. Wenn einer der beiden Vertragstypen vorliegt, dann kann der Hersteller von dem Designer jedenfalls weder Nacherfüllung noch Nachlieferung verlangen. Schenker und Verleiher haften lediglich dann, wenn sie einen Fehler der Sache arglistig verschweigen und hieraus ein Schaden beim Beschenkten bzw. Entleiher entsteht (§ 524 bzw. § 600 BGB). Allerdings lässt sich die unentgeltliche, vertragliche Zurverfügungstellung eines OSH-Designs weder dem Vertragstyp der Schenkung noch jenem der Leihe eindeutig zuordnen. Denn eine Schenkung setzt eine Entreicherung, also eine dauerhafte Vermögensminderung auf Seiten des Schenkenden voraus (MüKoBGB/*Koch*, BGB, § 516 Rn. 6). Dies wäre bei OSH-Designs allein dann denkbar, wenn das Design urheberrechtlich oder patentrechtlich geschützt und dem Erwerber eine unentgeltliche Lizenz eingeräumt würde. Die Leihe wiederum setzt die Überlassung einer Sache, also eines körperlichen Gegenstands voraus; immaterielle Gegenstände sind nicht umfasst. Es wird teilweise vertreten, die Vorschriften über die Leihe entsprechend auf die unentgeltliche Überlassung nicht körperlicher Gegenstände anzuwenden (MüKoBGB/*Häublein*, BGB, § 598 Rn. 5). Allerdings ist die Leihe grundsätzlich zeitlich begrenzt und der Entleiher ist nach § 604 Abs. 1 BGB verpflichtet nach Ablauf der vereinbarten Zeit die „Sache" zurückzugeben. Dies passt im OSH-Kontext aus zwei Gründen nicht. Zum einen ist eine Rückgabe des OSH-Bauplans an den Designer nie vorgesehen und zum anderen sind OSH-Baupläne per definitionem veränderbar und dürfen weiterverbreitet werden, sodass sich der Gegenstand der Leihe verändern und ein Rückgabeerfordernis mit der freien Weiterverbreitung in Widerspruch stehen würde.

Die unentgeltliche, vertragliche Zurverfügungstellung eines OSH-Designs ist stattdessen als Vertrag *sui generis* einzuordnen. Viel spricht dabei dafür, auch auf diesen gesetzlich nicht geregelten Vertragstyp die Haftungsprivilegien der unentgeltlichen Verträge des BGB anzuwenden: Der Designer erhält – ebenso wie Schenker und Verleiher – keine Gegenleistung, weshalb eine Gewährleistungshaftung unangemessen streng wäre. Zudem ist zu berücksichtigen, dass die Besonderheit von OSH gerade darin besteht, dass jedermann die Baupläne verändern und weiterentwickeln kann; der Entstehungsprozess wird dokumentiert und ist offen einsehbar. Bei einem fehlerhaften Design bleibt dem Hersteller also immer noch die Möglichkeit, selbst Hand anzulegen und den Mangel auszubessern. Die Herstellung eines mangelfreien OSH-Produkts zu ermöglichen, liegt eben nicht allein und eindeutig im Verantwortungsbereich eines (einzigen) Designers, sondern ist idealerweise das Ergebnis kollaborativer Weiterentwicklung und iterativer Verbesserung.

**Entgeltliche Weitergabe des OSH-Designs**
Für den Fall, dass der Designer den OSH-Bauplan dem Hersteller nur gegen eine Gebühr zur Verfügung stellt, kann der Hersteller grundsätzlich Mängelgewährleistungsrechte geltend machen, d. h. er kann Nachlieferung oder Nacherfüllung vom Designer verlangen, §§ 437 Nr. 1, 439 BGB. Weiterhin kann der Hersteller bei Vorliegen eines Mangels und dem Eintreten eines Schadens unter zusätzlichen Voraussetzungen Schadensersatz von dem Designer verlangen, §§ 437 Nr. 3, 280 ff. BGB. Voraussetzung für die Mängelgewährleistung ist immer, dass ein Mangel bei Gefahrübergang vorliegt. Das heißt, der OSH-Bauplan muss im Zeitpunkt des Downloads oder der sonstigen Zurverfügungstellung an den Hersteller mangelhaft sein.

§ 434 Abs. 1 BGB definiert, wann eine Sache frei von Sachmängeln ist, und ermöglicht durch einen Umkehrschluss festzustellen, wann ein Sachmangel vorliegt. Eine Sache ist dann frei von Sachmängeln, wenn sie den subjektiven und den objektiven Anforderungen entspricht. Den subjektiven Anforderungen entspricht die Sache, wenn sie die vereinbarte Beschaffenheit aufweist und sich für die nach dem Vertrag vorausgesetzte Verwendung eignet, § 434 Abs. 2 BGB. Die objektiven Anforderungen beinhalten, dass die Sache sich für die gewöhnliche Verwendung eignet und eine Beschaffenheit aufweist, die bei Sachen derselben Art üblich ist und die der Käufer erwarten kann, § 434 Abs. 3 BGB.

Welche objektiven Anforderungen an OSH-Baupläne zu stellen sind, ist nicht ganz leicht zu beurteilen. Zum einen bereitet es Schwierigkeiten zu bestimmen, welche Beschaffenheit bei Sachen derselben Art im OSH-Kontext üblich ist. In dem Zusammenhang stellt sich die Frage, mit welchen anderen Sachen OSH-Baupläne zu vergleichen sind. Unklar ist, ob sich dieselbe Art auf alle anderen Baupläne eines solchen Produktes bezieht oder nur auf OSH-Baupläne desgleichen Produktes. Zum anderen ist es schwer zu ermitteln, welche Beschaffenheit der Käufer erwarten kann, da auch Laien OSH-Baupläne erstellen und so Designer eines OSH-Produktes sein können. Die Vergleichsgruppe ist grundsätzlich mithilfe von Produktart und Produkttyp, Preiskategorie und anhand funktionaler Aspekte zu bestimmen (*Rockstroh/Peschel*, NJW 2020, S. 3345, 3346 Rn. 12). Demnach spricht viel dafür, dass als Vergleichsgruppe für die übliche Beschaffenheit eines OSH-Bauplans nur auf OSH-Baupläne desgleichen Produkts abzustellen ist. Die übliche Beschaffenheit bestimmt sich nach der Erwartung, die ein durchschnittlich informierter und objektiver Hersteller an die Beschaffenheit des OSH-Bauplans hat. Darin einfließen können die Angaben und Bezeichnung des OSH-Bauplans, etwa, wenn sich aus der Beschreibung ergibt, dass es sich um eine „Beta-Version" handelt. Auch einfließen können andere Beschreibungen und Äußerungen des Designers, beispielsweise wenn dieser ausdrückt, dass der OSH-Bauplan besonders sicher oder qualitativ hochwertig ist, dann kann der Hersteller höhere Erwartungen an den OSH-Bauplan stellen.

Die subjektiven und objektiven Anforderungen stehen gleichrangig nebeneinander. Die objektiven Anforderungen können aber durch die Parteien vertraglich (und auch konkludent) modifiziert oder abbedungen werden, § 434 Abs. 3 S. 1 BGB. In einem solchen Fall richtet sich der Mangelbegriff nur nach den subjektiven Anforderungen.

### 11.4.3 Haftung auf das Integritätsinteresse (Haftung für Schäden an anderen Rechtsgütern)

Das Integritätsinteresse ist das Interesse des Gläubigers an der Erhaltung seines *status quo*, also des ohne die geschuldete Leistung bestehenden Vermögensstatus. Es umfasst im Fall eines fehlerhaften OSH-Designs also vor allem Schäden an Eigentum oder Gesundheit des Herstellers bzw. des Nutzers des OSH-Produktes.

**Vertraglicher Schadensersatzanspruch**
Es ist wichtig zu ermitteln, ob zwischen dem Designer und dem Hersteller bezüglich der Zurverfügungstellung des OSH-Bauplans ein Vertrag vorliegt, denn ein Vertrag stellt eine Sonderverbindung dar, die dazu führt, dass die Vertragsparteien grundsätzlich höhere Sorgfaltspflichten beachten müssen, als würde zwischen ihnen keine solche vertragliche Sonderverbindung bestehen.

Eine weitreichende Bedeutung hat die Ermittlung, ob ein Schuldverhältnis besteht auch im Rahmen des vertraglichen Schadensersatzanspruches. Zum einen ist der Umfang des vertraglichen Schadensersatzes sehr weit und erfasst auch den Ersatz von bloßen Vermögensschäden. Zudem besteht eine Beweislastumkehr zugunsten des Anspruchstellers (§ 280 Abs. 1 S. 2 BGB), der typischerweise der geschädigte Hersteller sein wird. Dieser hat im Rahmen des vertraglichen Schadensersatzanspruchs lediglich darzulegen und zu beweisen, dass der Designer eine Pflicht aus dem Schuldverhältnis verletzt hat. Dagegen muss er nicht darlegen und beweisen, dass der Designer die Pflichtverletzung auch zu vertreten hat, d. h. vorsätzlich oder fahrlässig verletzt hat (§ 276 Abs. 1, 2 BGB). Bei Vorliegen eines Vertrages ist dem Designer auch das Verschulden derjenigen zuzurechnen, die er zur Erfüllung der vertraglichen Verbindlichkeiten einsetzt § 278 S. 1 Alt. 2 BGB (= Erfüllungsgehilfen) ohne, dass der Designer sich diesbezüglich exkulpieren kann.

Vertraglich schuldet der Vertragspartner nicht nur die Erfüllung der Leistungspflichten (= Äquivalenzinteresse), sondern hat auch Rücksicht auf die Rechte, Rechtsgüter und Interessen des anderen Teils zu nehmen (Integritätsinteresse). Konkret bedeutet das, dass der Designer dafür Sorge tragen muss, dass durch die Zurverfügungstellung eines OSH-Bauplans die Rechtsgüter des Herstellers nicht verletzt werden. Für die Konkretisierung des Umfangs der Schutzpflichten ist auf den Inhalt des Schuldverhältnisses abzustellen (NK-BGB/*Krebs*, BGB, § 241 Rn. 22). So richten sich Inhalt und Umfang der Nebenpflichten nach den vertraglichen Abreden der Parteien und den konkreten Umständen des Einzelfalls (BeckOK BGB/*Sutschet*, BGB, § 241 Rn. 44). Dabei ist desto eher von der Verletzung einer Nebenpflicht auszugehen, je mehr die Parteien auf eine vertrauensvolle Zusammenarbeit angewiesen sind oder der Hersteller sich auf die besondere Fachkunde des Designers verlassen können muss (BeckOK BGB/*Sutschet*, BGB, § 241 Rn. 44). Bei der Ermittlung in welchem Maße Schutzpflichten des Designers bestehen, sind auch die von dem OSH-Bauplan ausgehenden drohenden Gefahren zu berücksichtigen. Bei den Pflichten ist zwischen dem Verbot der aktiven Schädigung, der Pflicht zum aktiven Schutz und Informationspflichten zu unterscheiden (NK-BGB/*Krebs*, BGB, § 241 Rn. 22).

**Deliktischer Schadensersatzanspruch**
Dem Hersteller oder Nutzer kann gem. § 823 Abs. 1 BGB auch ein deliktischer Schadensersatzanspruch gegen den Designer zustehen. Ein solcher Anspruch setzt eine Rechtsgutsverletzung des Herstellers oder Nutzers voraus, welche durch ein vorsätzliches oder fahrlässiges Verhalten des Designers verursacht wurde. Durch § 823 Abs. 1 BGB geschützt sind absolute Rechtsgüter, wie etwa Leben, Gesundheit oder Eigentum. Ist ein solches durch das vorsätzliche oder fahrlässige Verhalten des Designers zu Schaden gekommen, kann der Hersteller oder Nutzer Ersatz verlangen. Im Gegensatz zum vertraglichen Schadensersatzanspruch ist der Anspruch aus § 823 Abs. 1 BGB auf die dort genannten Rechtsgüter beschränkt; Vermögensschäden sind über diese Vorschrift nicht zu ersetzen. Zudem muss der Anspruchssteller grundsätzlich darlegen und beweisen, dass der Anspruchsgegner die Rechtsgutsverletzung zu vertreten hat, das heißt vorsätzlich oder fahrlässig verursachte.

Im Kontext von OSH kann die Kausalität zwischen der Handlung des Designers und der Rechtsgutsverletzung auf Seiten von Hersteller bzw. Nutzer Schwierigkeiten bereiten: Der Designer haftet nur dann, wenn es gerade der von ihm oder ihr erstellte Bauplan war, der den Schaden verursacht hat. Nimmt der Hersteller Veränderungen am Bauplan vor oder kommt es während des Herstellungsprozesses zu Abweichungen vom Originalplan, kann es schwer sein, nachzuweisen, dass der Designer für den Schaden verantwortlich ist. Die Besonderheiten von OSH sind zudem – wie schon bei der vertraglichen Haftung – auch beim Verschuldensmaßstab angemessen zu berücksichtigen. Der Designer eines OSH-Bauplans sieht diesen möglicherweise nicht als finale Version, sondern lediglich als Entwurf an, der von anderen weiterbearbeitet und verbessert werden soll. Wird dies ausreichend kenntlich gemacht, sind geringere Anforderungen an die vom Designer aufzuwendende Sorgfalt zu stellen.

**Anspruch aus dem Produkthaftungsgesetz (ProdHaftG)**
Neben der vertraglichen und deliktischen Haftung gibt es im deutschen Haftungsrecht noch die verschuldensunabhängige Produkthaftung aus dem Produkthaftungsgesetz (ProdHaftG). Nach dem ProdHaftG haftet der „Hersteller", wenn durch Inverkehrbringen eines fehlerhaften Produktes Schäden an bestimmten Rechtsgütern des Anspruchsstellers eintreten (BeckOKG/*Seibl*, ProdHaftG, § 1 Rn. 2). Die Haftung nach dem ProdHaftG ist an das Inverkehrbringen eines fehlerhaften Produkts geknüpft. Ein Verschulden des Herstellers i. S. einer persönlichen Vorwerfbarkeit ist nicht erforderlich (MüKoBGB/*Wagner*, ProdHaftG, Einleitung ProdHaftG Rn. 17). Die Produkthaftung aus dem ProdHaftG ist damit besonders streng. Der Designer eines OSH-Bauplans muss allerdings nur dann mit Ansprüchen aus dem ProdHaftG rechnen, wenn er selbst als „Hersteller" iSd ProdHaftG anzusehen ist und der von ihm erstellte OSH-Bauplan ein Produkt iSd ProdHaftG ist.

Das ProdHaftG dient der Umsetzung der europäische Produkthaftungsrichtlinie (ProdHaftRL). Die ProdHaftRL ist in ihrer aktuell gültigen Fassung nicht für die digitale Wirtschaft sowie Kreislaufwirtschaft im Allgemeinen und OSH-Produkte im Speziellen aus-gelegt. Die Vorgaben der ProdHaftRL entsprechen nicht der technologischen Entwicklung der letzten Jahre, da digitale Anwendungen unberücksichtigt sind und sich seit dem Erlass der ProdHaftRL im Jahr 1985 die Art und Weise wie Produkte hergestellt, vertrieben und betrieben werden erheblich verändert hat (siehe Nr. 1: Bundesrat, Begründung des Richtlinienentwurfs für eine neue Produkthaftungsrichtlinie, S. 2). Deshalb hat die europäische Kommission im September 2022 einen Entwurf für eine neue Produkthaftungsrichtlinie (ProdHaftRL-E) vorgelegt (siehe Nr. 4: European Commission, Richtlinienvorschlag über die Haftung für fehlerhafte Produkte des Europäischen Parlamentes und Rates). Die ProdHaftRL-E beabsichtigt eine umfassende Modernisierung der verschuldensunabhängigen Haftung für fehlerhafte Produkte. Nach der ProdHaftRL-E sollen künftig auch Software und digitale Bauunterlagen (Produktionsdateien) unter den Anwendungsbereich der Produkthaftungsrichtlinie fallen (siehe Artikel 4 (1) ProdHaftRL-Entwurf). Das ist eine wichtige Ergänzung, die die viel diskutierte Frage, ob Software oder OSH-Baupläne als Produkte iSd § 2 ProdHaftG anzusehen sind, klären würde.

Relevant für den OSH-Kontext ist auch Erwägungsgrund 13 (ErwG) der ProdHaftRL-E, wonach die ProdHaftRL nicht für freie und quelloffene Software gelten soll, die außerhalb einer gewerblichen Tätigkeit entwickelt oder bereitgestellt wird, um Innovation und Forschung nicht zu behindern. Möglicherweise sind damit auch unentgeltlich zur Verfügung gestellte OSH-Baupläne aus dem Anwendungsbereich der ProdHaftRL-E ausgenommen, was zwingend auch zu einer Privilegierung im nationalen Recht führen würde: Da die ProdHaftRL grundsätzlich vollharmonisierend ist, dürfen die EU-Mitgliedstaaten von der ProdHaftRL abweichende nationale Rechtsvorschriften weder aufrechterhalten noch einführen (siehe Artikel 3 ProdHaftRL-E). In der ProdHaftRL-E findet sich allerdings kein Hinweis darauf, ob OSH von ErwG 13 erfasst ist. Die Ratio des Erwägungsgrunds passt auch für OSH-Baupläne, denn diese sollen offen geteilt werden, frei zugänglich, nutzbar, veränderbar und weiterverteilbar sein und bergen ein enormes Innovationspotenzial. Andererseits differenziert die ProdHaftRL-E explizit zwischen Software und „digital manufacturing files“, wozu auch OSH-Baupläne zählen. Aus rechtswissenschaftlicher Sicht ist es spannend zu ermitteln, ob dieser Erwägungsgrund auch auf OSH übertragbar ist und die unentgeltliche Weitergabe von OSH folglich durch die ProdHaftRL-Ef privilegiert wäre.

Im Geltungsbereich der ProdHaftRL-E wäre bei der Ermittlung, ob ein OSH-Bauplan fehlerhaft ist, darauf abzustellen, ob der OSH-Bauplan die Sicherheit bietet, die die Allgemeinheit unter Berücksichtigung der Umstände erwarten darf (vgl. Artikel 6 Abs. 1 ProdHaftRL-E). Auch hier ist wieder relevant, welche Anforderungen an einen OSH-Bauplan zu stellen sind. Im OSH-Kontext ist auch Art. 7 Abs. 4 ProdHaftRL-E relevant. Hiernach ist jede natürliche oder juristische Person als Hersteller anzusehen, die ein bereits in Verkehr gebrachtes oder in Betrieb genommenes Produkt verändert in den Verkehr gebracht hat, wenn die Änderung des bezeichneten Produkts als wesentlich gilt und außerhalb der Kontrolle des ursprünglichen Herstellers erfolgt.

Grundsätzlich muss der (geschädigte) Anspruchssteller den Produktfehler, den Schaden und den Kausalzusammenhang zwischen beiden beweisen, siehe Artikel 9 Abs. 1 ProdHaftRL-E. Die Fehlerhaftigkeit des Produkts und die Kausalität des Fehlers für den

Schaden wird aber zukünftig widerlegbar vermutet, wenn die Beweisführung aufgrund der technischen und wissenschaftlichen Komplexität übermäßig schwierig ist. In diesem Fall ist nur nachzuweisen, dass das Produkt wahrscheinlich fehlerhaft war und zum Schaden beigetragen hat, siehe Artikel 9 Abs. 2 ProdHaftRL-E. Bislang haben Geschädigte im Falle einer Sachbeschädigung einen Schaden bis zu einer Höhe von 500 € selbst zu tragen, § 11 ProdHaftG. Dieser Selbstbehalt soll künftig entfallen, Art. 13 ProdHaftRL-E. Zudem soll auch die Haftungshöchstgrenze von 85 Mio. € entfallen.

## 11.5 Ausblick

Der Kurzbeitrag hat am Beispiel des Designers eines OSH-Produkts einen Überblick über die relevantesten Haftungsgrundlagen gegeben und aufgezeigt, an welchen Stellen die Besonderheiten von OSH das Haftungsrecht vor Herausforderungen stellt. Neben der Anfertigung von Guidelines unter anderem zum Haftungsrecht, die insbesondere auch mögliche Haftungsrisiken von OSH-Herstellern und Fab Lab-Instrukteuren abdeckt, sollen zwei Themen im Fokus der weiteren Forschung stehen:

Zum einen die Bestimmung objektiver Anforderungen an OSH-Produkte sowie der an das Verhalten der Akteure anzulegende Sorgfaltsmaßstab. Zum anderen sollen etwaige gesetzliche Haftungsprivilegierungen für die OSH-Produktion identifiziert und auf ihre Tragfähigkeit untersucht werden. Das Haftungsrecht sieht teilweise bereits Privilegierungen für unentgeltliche Leistungen vor, etwa im Schenkungsrecht oder bei der Leihe. Auch der Entwurf für die neue ProdHaftRL enthält eine Privilegierung für offene, nicht proprietäre Produkte, die sich allerdings explizit nur auf Software bezieht. Die zugrunde liegenden Erwägungen lassen sich möglicherweise auf OSH übertragen. Hinzu tritt die Besonderheit, dass OSH oft altruistischen Zwecken dient, nämlich der Erzielung eines Mehrwerts für die Gesellschaft und von nachhaltigerer Wertschöpfung. Es stellt sich die Frage, inwieweit der altruistische Zweck einer Tätigkeit sowie Aspekte von Gemeinwohl und Nachhaltigkeit im geltenden Haftungsrecht berücksichtigungsfähig sind. Festzuhalten ist, dass der Erfolg der geteilten Produktion im OSH-Kontext maßgeblich auch davon abhängig ist, ob die einzelnen Akteure potenzielle Haftungsrisiken überblicken und einschätzen können, welchen Sorgfaltsmaßstab sie bei der Herstellung von OSH-Bauplänen oder OSH-Produkten anlegen müssen.

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# Teil III

# Distributed Innovation, Design, and Product Development

# Citizen Innovation in Fab Cities

12

## How Do Participation Motives Influence the Quality of Ideas?

Johanna Schnier, David Pacuku, Christina Raasch
and Manuel Moritz

## 12.1 Introduction

Organizations increasingly use competitions (or challenges/contests) to elicit solutions to problems that they face (Boudreau et al., 2011; Mihm & Schlapp, 2019). When hosting such competitions, organizations formulate a problem at the outset and issue an open call, inviting individuals from outside the organization to come up with solutions. Those individuals who contribute the solution deemed best receive a prize. By hosting such competitions, organizations can tap into valuable knowledge that they lack internally (Piezunka & Dahlander, 2015; Jeppesen & Lakhani, 2010), and increase their visibility with audiences that they otherwise would not have reached.

Competitions have been historically important in pushing science and innovation. In the fifteenth century, the city of Florence offered a prize to the individual who would find a way of building the widest and tallest cathedral dome (Jeppesen & Lakhani, 2010). In the eighteenth century, the British Parliament offered a prize to the individual who would reliably determine longitude at sea (Boudreau et al., 2011). More recently, governments across the globe reached out to citizens to elicit ideas on how to fight the pandemic.

In this vein, Fab City Hamburg organized a challenge to elicit ideas for "social, sustainable, and innovative products that can be produced locally". Ideas should be simple enough to be implemented by anyone with access to the machinery (e.g., 3-D printers) found in

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one of the several Fab Labs. The winners would be given the opportunity to further develop their ideas into prototypes in a professional workshop, a possible door opener towards the commercialization of their products.

As organizations more and more often resort to innovation challenges as a mechanism to solve problems, research on innovation challenges has flourished. Questions in this stream of research include, among many others, how many participants organizations should admit to competitions (Boudreau et al., 2011), and what kind of feedback they should give participants (Mihm & Schlapp, 2019). In their influential study from 2010, Jeppesen and Lakhani explored the characteristics of participants who contributed the most valuable (that is, winning) ideas. Focusing on the distance between participants' technical expertise and the area to which the problem pertains, they find that marginal individuals – i.e., those whose own expertise is un- or only faintly related to the problem at hand – provide the most valuable solutions. This finding has provided important insights into the kind of individuals who organizations should target with these competitions: organizations should seek to engage individuals whose field of expertise is relatively distant to the focal area of the problem.

However, despite the importance of this study in advancing the discipline's understanding of the relationship between individual background characteristics and idea value, there are many other individual-level characteristics that are plausibly predictive of idea value but have not received any attention from literature. Specifically, individuals' motivation to participate in challenges might be systematically related to the value of the solutions they propose. In fact, prior research suggests that individuals whose primary participation motive is of a non-financial nature (e.g., peer recognition, joy of innovating) outperform those who are primarily financially driven (Ederer & Manso, 2013). If individuals produced differential idea values depending on their participation motive, this would have powerful implications on the competition designs, specifically with respect to prizes. In this article, we shed light on the relationship between participation motives and innovation performance.

## 12.2 Theoretical Background

Past innovation research has extensively studied what motivates individuals to engage in innovative activities. Until the 1990s, the dominant answer to this question was profit-seeking: individuals engage in innovation expecting pecuniary rewards – they come up with, develop, and implement innovative ideas because they expect to generate profit from them.

While profit-seeking motives might be one reason why individuals engage in innovation, research in the 2000s began to point out that such profit-seeking motives cannot sufficiently explain innovative activities. Most famously perhaps, Lerner & Tirole (2003, 2005) asked in the light of the growing open-source movement: "Why should thousands of top-notch programmers contribute freely to the provision of a public good?" By openly revealing and sharing their code with others, programmers forgo profit-seeking opportunities, suggesting that they are driven by other motives.

Subsequent research sought to identify the various motives driving innovative activities. Broadly speaking, these motives can be categorized into extrinsic and intrinsic ones. Individuals are extrinsically motivated if they expect to derive some benefit from an external environment (Ryan & Deci, 2000; Sauermann & Cohen, 2010). This external environment might be a peer community if individuals engage in innovative activities to gain peer recognition, or it might be a market if individuals seek profits from their innovative activities. As such, profit-seeking is one extrinsic motive (of several) to engage in innovative activities. On the other hand, individuals are intrinsically motivated if they derive benefits from the innovative activity itself. For example, individuals are driven by intrinsic motives if they derive great joy from a certain activity or if they have a deep interest in a certain field.

While a large body of research has investigated the various motives that drive individuals to engage in innovative activities, there is very scant research on how these motives relate to innovation performance. For example, do individuals who engage in innovative activities out of profit-seeking motives produce more or less valuable innovations than those who are driven by peer recognition? Sauermann and Cohen (2010) explored (in a company context) how employees' innovation motives relate to their innovation performance. They find that employees who are driven by intellectual challenge, independence, and money produce more valuable innovations than those whose primary motives are job security and greater levels of responsibility. However, it is unclear how these findings generalize to the case of competitions where motives such as job security and levels of responsibility do not apply and independence is, by design, a given. At the same time, understanding how innovation motives are related to innovation performance in competitions is key for organizations that wish to attract the most valuable ideas. If organizations know which motives yield the most valuable ideas, they can target individuals and select prizes accordingly.

## 12.3 Empirical Context

The Fab City Hamburg Maker Challenge provides an ideal setting to study the relationship between individuals' innovation motives and innovation performance. This challenge took place in June 2022 with the goal of eliciting and rewarding ideas that would help make Hamburg a more social, sustainable, and self-sufficient city. As a prize, the individuals with the top-20 ideas would be invited to a prototyping workshop that would help them develop their ideas into a fully-fledged product. In addition, the best idea would win a 3-D printer. Individuals had roughly four weeks to submit ideas. After that, they had to specify why they wanted to participate in the challenge. They could choose from the following options: "I participate in the Maker Challenge …

- … for altruistic reasons."
- … to contribute to the community."
- … to experiment with 3-D printing."
- … to make Hamburg a better place."
- … to turn my ideas into a startup."
- … to learn from feedback."
- … for financial rewards."

Once the submission deadline had passed, the ideas were evaluated by citizens in a pairwise comparison: citizen-voters were shown randomly paired ideas and had to indicate their preference. Any citizen based in Hamburg could vote, provided they had signed up. The ideas were ranked according to who had won pairwise comparisons, with those ideas winning pairwise comparisons the most often at the top. Based on this ranking, the top 35% of ideas were identified, and then assessed by expert judges in (again) pairwise comparisons. These expert votes formed the basis for the final ranking of ideas.

## 12.4 Descriptive Statistics

Ninety distinct individuals submitted 110 ideas. As illustrated in Fig. 12.1, individuals most often participated in the competition for altruistic reasons (42%), followed by the desire to contribute to the community (21%), to experiment with 3-D printing (13%), to learn from feedback (7%), to turn their idea into a startup (6%), for financial rewards (5%), and to help make Hamburg a better place (2%). Thus, financial rewards played only a minor role as driving force for participation.

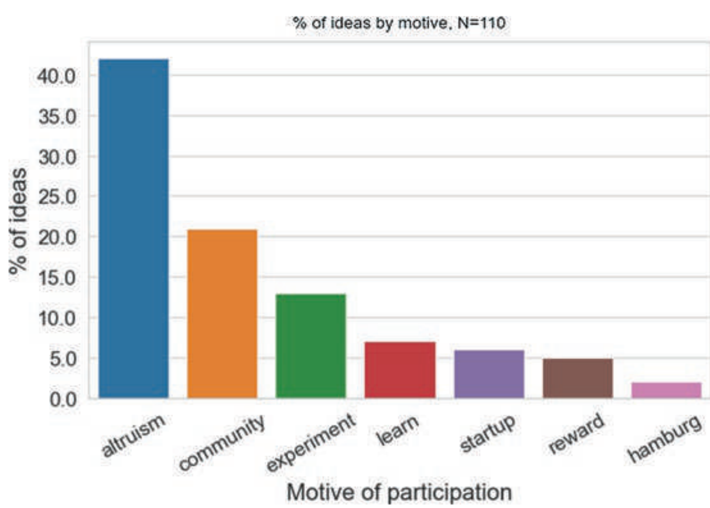


**Fig. 12.1** % of ideas by motive, N = 110

Next, descriptively, we examine how the various motives relate to performance in the competition. We consider two performance outcomes:

1. Did an idea score well enough in the citizen voting to make it to the top 35% and be assessed by experts?
2. If assessed by experts, which expert score did ideas receive?

Thus, the first performance outcome variable is binary (1 if an idea made it to the top 35%, 0 if not). The second performance outcome, the expert score, is a continuous variable that takes any value between 1 (best possible) and 0 (worst possible). This expert score represents the share of pairwise comparisons won by an idea. For example, an idea has an expert score of 0.7 if it won 70% of the pairwise comparisons; an idea has an expert score of 0.1 if it won 10% of the pairwise comparisons. By construction, the mean expert score is 0.5.

We see in Fig. 12.2 that those individuals whose primary motive to participate in the competition was altruism were also the ones with the most valuable contributions as assessed by the citizen judges. Almost half (48%) of the ideas that were submitted by altruistically motivated individuals made it to the top 35% of ideas, followed by 43% of the ideas submitted by individuals whose primary motive was to turn their ideas into a startup. Those who participated in the competition to derive financial rewards had a success rate of 33%, which is 15% points below the altruistically motivated ones. Those who participated to experiment with 3-D printing had the lowest success rate (22%), possibly because they lacked any prior experience with 3-D printing.

Next, we examine how expert (rather than citizen) votes vary depending on participation motives, provided an idea made it to the top 30%. Figure 12.3 shows, evaluation out-

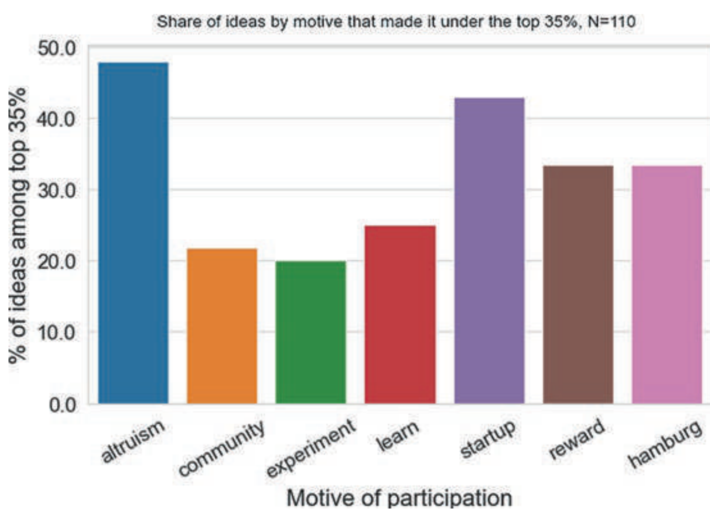


**Fig. 12.2** Share of ideas by motive that made it under the top 35%, N = 110

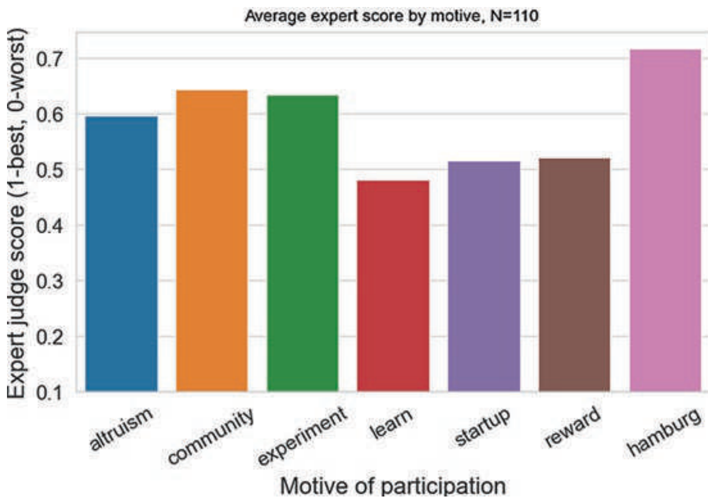


**Fig. 12.3** Average expert score by motive, N = 110

comes no longer differ as strongly with participation motives as above. Those whose primary participation motive was to make Hamburg a better (more sustainable and social) place received, on average, the most favorable expert score (0.62). Note, however, that this finding is generated based on one observation only: three individuals indicated that they participated to make Hamburg a better place, and of those only one made it to the top 35%. Hence, this finding does not allow for any solid inferences. Those whose primary motive was to learn from feedback received, on average, the lowest scores (0.38). Those whose primary participation motive was altruism received an average score of 0.51, which is slightly above the overall average score. Hence, if innovation motives are at all predictive of innovation performance as measured by expert votes, altruistic motives are associated with superior innovation performance.

## 12.5 Inferential Statistics

We also estimated the relationship between participation motives and innovation outcome in a series of regression models. Specifically, we predicted the likelihood of ideas to become top 35% based on participation motives. Using logistic regressions, we found that ideas that were submitted for altruistic reasons were more than 3.2 times more likely to become top 35% than ideas that were submitted with a community motive ($p < 0.05$), and more than 3.6 times more likely to become top 35% than ideas that were submitted with an experimentation motive ($p < 0.1$). Results from linear probability models point in the same direction: compared with the altruistic individuals with a community (experimentation) motive had a 30% (28%) lower probability of ideas ending up in the top 35%. We did not find any evidence that participation motives other than community and experimentation mattered relative to altruism. We also did not uncover any statistically significant relationships in the second stage of the voting process, i.e., the expert voting, which is hardly surprising given the small sample size of 38 ideas.

## 12.6 Conclusion

Organizations across industries rely on challenges to elicit ideas to problems that they face. Challenges have thus become a key determinant of organizations' innovation performance and continue to grow in importance as the knowledge required for successful innovation is increasingly distributed over a wide number of individuals inside – and outside – organizations. Given the importance of innovation challenges for organizational life, a growing body of research has investigated various questions related to innovation challenges: how many individuals should participate in competitions? Should participants receive feedback? Which individual background characteristics are predictive of innovation performance? The latter question has, surprisingly, remained rather less explored than expected. Specifically, individuals' motivation to participate in challenges has not been considered as a determinant of their innovation performance in challenges. Yet, understanding the relationship between participation motives and innovation performance is key for organizations to target the 'right' individuals and to design prizes accordingly.

Leveraging the Fab City Hamburg Maker Challenge as an empirical context, this article attempts to fill this gap. After individuals had submitted their ideas to the contest, we asked them why they had done so. This information, together with the citizen and expert votes of ideas, allowed us to uncover links between participation motives and innovation performance. We found that those individuals with altruistic participation motives scored best with the citizen judges: almost half of their ideas made it to the top 35%, and hence to the next round of expert voting. Besides this descriptive evidence, we also found, based on logistic regressions, that individuals whose primary participation motive related to experimentation and community were substantially less likely to have their ideas chosen by citizens than altruistically motivated individuals. We could not replicate this finding in the second stage of the voting process, when expert judges assessed the top-35% ideas. This, however, is not surprising given the very limited sample of 38 ideas in this second stage.

This study comes with several limitations. First, it is based on (non-experimental) survey evidence, precluding any causal interpretation of the found results. Specifically, it is possible that participation motives are related to other unobserved variables that influence idea quality, and that this is what drives the relationship between participation motives and idea quality. For example, it is very likely that participation motives are related to prior experience in developing ideas, and that this experience also drives idea quality. Individuals who indicate an experimentation motive might have no or very little prior experience with 3-D printing, and this lack of experience might result in a low-quality idea. At the same time, individuals with altruistic motives believe by definition that others might benefit from their ideas, which might go hand in hand with higher-quality ideas. In this study, we were unable to control the influence of such unobserved variables. Future research should thus examine the effect of participation motives on the quality of ideas, and innovation performance more generally, experimentally.

Another limitation is that our results likely suffer from selection bias. Winners were promised a 3-D printer as well as the opportunity to participate in a prototyping workshop. As such, the competition attracted few individuals with pecuniary motives while speaking first and foremost to those with altruistic motives. Unsurprisingly, almost half of the participants indicated altruism as a participation motive. The choice of a prize means that our sample of participants is not representative of the general population. Future challenges should use different prizes to forestall such selection effects.

What implications can we draw based on our evidence that the quality of ideas tends to be especially high with altruistically motivated participants? Future Fab City challenges should target individuals that score high in altruism. To attract these individuals, prizes should be designed accordingly. The altruistic are unlikely to be attracted by monetary rewards. Rather, prizes should give participants a platform to further diffuse their ideas and help others implement their ideas. If the altruistic derive benefits from seeing others implement and use their ideas, this should be facilitated through (online and on-site) workshops that involve both innovators (or challenge winners) and users. As such, the prototyping workshops – though a right first step – should also involve potential users.

More generally, the Fab City Hamburg maker challenge demonstrates that involving citizens in innovation activities, e.g., via innovation competitions, bears great potential for a realization of the goals spelled out by the Fab City Manifesto, which is, among others, to make production more local, to encourage citizens to share their knowledge, and to make innovation more inclusive.

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# 13 Barriers to Widespread Adoption of Fab City Products

## A User (Innovator) Perspective

Marvin Klein and Christian Lüthje

## 13.1 Introduction

Just as one swallow does not make a summer, one Fab Lab (fabrication laboratory) does not make a "Fab City". To really earn this status, the maker movement needs to reach not just a small group of tech-savvy individuals but many citizens.

The concept of Fab City stems from the Fab Lab movement – a global network of open workshops initiated by Prof. Neil Gershenfeld at Massachusetts Institute of Technology (MIT) in the early 2000s. Fab Labs provide access to manufacturing technologies (e.g., 3-D printers, laser cutters, CNC mills) as well as the necessary skills and materials. A city becomes a Fab City if it joins the global initiative and ensures that access to these Fab Labs is as low-threshold as possible for citizens. The vision is that products of the future will be designed globally but manufactured locally. This method of production is called digital manufacturing as it utilizes, inter alia, computer-aided designs (CAD). As every citizen has the possibility to become a user innovator by developing product designs, finally, not only production but also innovation shall be more decentralized.

Depending on the country, between 1.5% and 9.6% of the population are user innovators (for an overview: Jin et al., 2018). Fortunately, most of these have no problem with making their ideas open-source (von Hippel, 2006). However, recent studies indicate that innovators often have no real incentive to bear the costs of active diffusion efforts (de Jong et al., 2015), such as easy-to-understand documentation or marketing. Social welfare losses result from this so-called diffusion shortfall (von Hippel, 2017; Franke & Lüthje, 2020). Further reasons user innovators hesitate to share their ideas in the first place are

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legal concerns, for instance, about their intellectual property (IP) rights or liability issues. However, sometimes producers are responsible for this diffusion shortfall as they frequently underestimate the potential of user innovations and, thus, do not adopt them (von Hippel, 2017; Bradonjic et al., 2019).

The diffusion of user-generated designs is both complex and exciting for innovation research. Unlike for most innovations, not only potential adoption barriers on the end user's side must be overcome but also those hindering user innovators from sharing their ideas. Therefore, in this conceptual paper, we provide an overview of factors that may prevent a diffusion of products designed for production in Fab Labs. We focus on factors that apply both, on the level of the product designers as well as on the level of potential adopters of products generated in Fab Labs. Thus, our contribution is threefold. In Sect. 13.2, we present voluntary payment methods that might incentivize user innovators to take on diffusion efforts. Next, in Sect. 13.3, we discuss how Fab Cities can help overcome legal concerns user innovators potentially deal with. In Sect. 13.4, we take a closer look at consumers and introduce methods that may be used to overcome potential adoption barriers. Finally, our contribution concludes in Sect. 13.5.

## 13.2 Monetary Incentives in Open Source

Users of products and services constitute an important source of innovation (von Hippel, 2006). There is a high number of documented examples showing that major first-of-type innovations originated from users (e.g., windsurfing, airplanes, the world wide web). In addition, there is a large body of studies showing that user innovation is not a rare but a rather frequent phenomenon in many different industries (von Hippel et al., 2012; Franke et al., 2016). User innovation is not limited to firms and technological professionals. Also, private households and citizens are in a good position to develop improved or completely new products (von Hippel, 2017). Cost-effective design and prototyping tools make it feasible for many household innovators to design and build new product solutions. These tools are now affordable and, even more importantly, easily accessible via Fab Labs (Wolf & McQuitty, 2013; Weller et al., 2015; Whitson et al., 2018). In addition, the internet facilitates the interaction between creative users in communities and dedicated development projects (Franke & Lüthje, 2020). Hence, households and citizens have the potential to become the backbone of the invention, design, prototyping, and manufacturing activities unfolding by and in Fab Labs.

Several research studies demonstrate that user innovation activities are triggered by other motives and expectations than innovation work carried out by firms. The main reason why users innovate is to find solutions for themselves that best fit their individual needs (von Hippel et al., 2011, 2012; de Jong & von Hippel, 2013; de Jong et al., 2015; Stock et al., 2015). Besides the expectation to benefit personally from the innovation, users are often motivated by several intrinsic and process-related benefits such as fun, altruism, or getting positive feedback from peers (Füller et al., 2008, 2009; Nambisan & Baron, 2009; Brabham, 2010; Füller, 2010). Users that are primarily driven by these self-rewarding aspects put less or even no attention to compensation or economic returns for their innovation effort. This is why most private innovators are willing to give up their intellectual property rights and to freely reveal their inventions to everyone (de Jong et al., 2015; von Hippel, 2017).

The self-rewarding character of user innovation work is both a curse and a blessing. It promotes the free revealing of ideas and product designs, but it also implies that user innovators have little incentive to drive a wide adoption of their innovations. After all, most benefits that motivate users to engage in innovation can be achieved without a broad diffusion. Furthermore, reaching a wider adoption is costly for the originators as it requires a dedicated effort to document the product designs so appropriately that others could rebuild them. Users would also need to invest resources to actively promote their inventions effectively and on a large scale. Consequently, self-rewarded innovators have been found to rarely engage in diffusion activities involving these physical costs (de Jong et al., 2015, 2018). This implies that user innovations may often fail to reach those potential adopters that may significantly benefit from them. This phenomenon that limits the potential impact of user innovation is often referred to as "diffusion shortfall" (von Hippel, 2017; von Hippel et al., 2017).

The question arises how the empirically documented problem of low levels of diffusion of user-generated product designs could be eliminated. One self-evident way to address this issue is to offer financial benefits to user firms and household innovators. Even though most users do not start to innovate because of financial considerations, the outlook of possible revenues might nonetheless motivate them to actively promote their ideas to others and to engage in practices that make it easier for others to adopt, build and use the innovations. If supporting a wider diffusion creates costs, innovating users may require financial returns to compensate for the costs that they personally incur.

Monetary returns for innovating users can be generated by adding a commercial path to the free and open-source model of Fab Labs. Like other online maker spaces for digital and physical goods, individual Fab Labs or networks of Fab Labs may seek to establish marketplaces where user innovators' property rights for their designs lie and through which a license price may be charged. These online platforms open easily accessible and low-cost paths to commercialization and ensure that users are directly compensated for taking the effort. However, establishing market models bear the risk of crowding-out the self-reward-oriented and intrinsically motivated innovation activities of user firms and households. It may have negative effects on Fab Lab communities in which open licenses, free revealing and mutual support constitute a very supportive context for the generation of innovative designs (West & Gallagher, 2006).

This is why other forms of financial compensation with a lower risk of losing the idea of an open-source community in which all ideas can be easily accessed, adapted, or even improved by others should be considered for user innovators. Systems based on voluntary payments are one interesting alternative to proprietary commercial models. Donations have been a very common practice in several areas, and tips given to service employees accumulate to substantial volumes (Azar, 2011). Voluntary payments to the originators of digital products are frequently used in open-source software and might transfer well to a Fab Lab context of open product designs (Natter & Kaufmann, 2015).

When thinking about voluntary payments, it is of particular interest to understand under which conditions models involving voluntary payment elements are more or less likely to generate significant and fair monetary compensation for the originators of product designs. Future research needs to investigate to what extent these drivers and inhibitors are relevant in the specific context of maker spaces and Fab Labs. The following factors seem to be of particular relevance:

**Anchoring** Kim et al. (2009) demonstrated in three field studies that the amount of voluntarily paid money in pay-what-you-want (PWYW) models depends on internal reference prices that customers use as an anchor. In the case of products manufactured in Fab Labs, customers could use the price of the next best commercial alternative as their internal anchor to determine the appropriateness of which voluntary payment. In this case, the average price of a similar product in stores would influence the paid price. However, it is also likely that customers of Fab Lab products would use the next-best free product designs that are offered for a prize of zero as their mental anchor. Obviously enough, this may significantly reduce the willingness to make considerable voluntary payments for product designs. We propose that future research should investigate how Fab Lab customers build internal price anchors and how the development of reference prices can be influenced by deliberately providing external reference prices. For example, one could investigate whether priming customers by simply asking them to think about how much the product would cost in the store leads to a higher voluntary payment.

**Product Costs** Different to the distribution of software, re-producing products is associated with variable costs. Therefore, product customers need to cover the costs of material and product manufacturing in the Fab Lab – even if the product design itself is offered for free. In this respect, the situation in most Fab Labs will differ from pure PWYW models commonly known in software. It would be very helpful to know how this mandatory cost-based price influences the willingness to pay the originator of a product design an extra tip. It might make a significant difference whether customers need to decide to pay voluntarily on top of a fixed price or rather decide whether to pay anything at all. On the one hand, paying voluntarily in pure PWYW models constitutes a more significantly perceived psychological effort than tipping the product designer in addition to a mandatory payment for production. This would imply higher voluntary payments in the context of Fab Labs. On the other hand, a fixed price reduces the customer rent and can therefore be expected to result in lower voluntary payments to the originator of the product designs. Research scholars should explore the magnitude of these opposite effects. Studies on the success of voluntary payment models in Fab Labs could contribute interesting differences to the studies that have been conducted on donation-based systems in free software.

Interestingly, the fixed price for covering a Fab Lab's production costs may also influence the internal reference price that customers develop in their heads. Customers may take the fixed price as an anchor when deciding the voluntary payment of the product design. In this respect, the two aspects of anchoring and non-voluntary product costs are partly interrelated.

**Relationship to Fab Cities** It has been repeatedly shown that the relationship between the payer and the provider of a product or service heavily influences the willingness to donate or tip. Consequently, a higher closeness usually leads to higher voluntary payments (Andreoni & Bernheim, 2009).

Fab Labs would need to enable customers who decide to make a product design a convenient online access to the facilities and machines. Ideally, the entire process of design scanning, product ordering and payment would happen via digital channels. While this online process is efficient, it constitutes a rather anonymous setting that could lead to a high psychological distance between customers and Fab Labs and, in turn, to rather low payments (Kim et al., 2014).

However, many customers of products generated and produced in Fab Labs may feel a strong connection to the basic objectives of a Fab Lab enriched economy. Fab Labs provide access to materials and production technologies to everybody allowing them to digitally design and produce solutions to their own needs. Therefore, the democratization of innovation is one of the key missions in most existing Fab Lab networks (Diez Ladera, 2016). Additionally, there are nuclei of maker communities of diverse inventors, designers, artists, and engineers which facilitates education, learning and innovation across domains. Fab Cities as well as several Fab Labs promote the idea of local production and a circular economy. All this indicates that customers should often develop a closer relationship to a Fab Lab than they usually do to a conventional retailer or online shop.

## 13.3 Legal Matters

In this chapter we discuss two exemplary legal matters that might hinder user innovators to share their ideas, namely, product piracy and liability concerns. These two are certainly not the only relevant legal matters, however, we picked them as we feel that they occur most frequently.

**Product Piracy Concerns** Free revealing of product designs is in contradiction to economic theory. Classic theory proposes that an innovator can hope to reap the profits associated with an innovation only if they manage to protect it by intellectual property rights (Teece, 1986). This is particularly important in markets for technologies or markets for designs in which licensing fees are the main source of revenue. The risk of uncompensated knowledge spillovers and uncontrolled generation of copies is very high for digital products (Peitz & Waelbroeck, 2006). Most notably, the insanely high product piracy and sharing of illegal copies of all kinds of media and software resulted in high financial losses for the software programmers, artists, and content creators. The risk of uncontrolled copying and sharing is also high for product designs in digital format (e.g., CAD files) which can be recreated by production technology accessible in Fab Labs.

Fortunately enough for user firms, independent designers, and household innovators, many product designs cannot be easily built by production technology that is commonly available, such as low-cost 3-D printers and other simple tools. More complex designs require more sophisticated equipment and support that is exclusively accessible in Fab Labs. Here, to avoid fraud, Fab Labs could, for instance, make sure that no pirated designs can be produced with their machines.

However, maybe the problem for user innovators is not the few end users copying their ideas secretly but the fear that a commercial company makes profit off it while they, being only a small fish in a shark tank, could do nothing about it. For this reason, the reliable and uncomplicated possibility to protect IP rights could not only lower the concerns of user innovators but also create a business model for Fab Labs. User innovators that could hire Fab Labs to protect the idea IP, while, in return, the Fab Lab – or Fab City as a brand – officially registers the rights, guarantees that plagiarisms cannot be illegally produced in any Fab Lab worldwide or assists with legal matters, such as when a large company is trying to steal the idea. Further research should, therefore, investigate whether such a service would lead to more user innovations being diffused and how much user innovators would be willing to pay for it.

Moreover, the provision of digital twins (Tao et al., 2018) for each product (thus guaranteeing the origin of design) could be beneficial and its implementation another business model for Fab Labs. Such a digital twin might play a key role for the offering or reselling of already produced designs on other platforms. Digital twins would also allow the user innovators to see what happened with their idea, meaning that it is possible to track the number of replicas made and where (e.g., a Fab Lab in Barcelona). Future research could, thus, investigate whether these statistics could work as an intrinsic motivation for user innovators. Moreover, if the digital twin is stored on a distributed ledger, it should be easily possible to pay the designer via micropayments over the ledger in the near future (Klein et al., 2022).

**Liability Risk** Digital twins cannot only guarantee a design's originality but also play an important role in terms of its warranty or liability issues. Liability in general is a big concern in terms of new products. In this context, user innovators might be afraid to share their designs as they do not want to be held responsible for damages. This might either be the case for designs that have not been tested several times already but also for designs that are technically solid but need a professional rework after laser cutting or 3-D printing it.

This, once again, offers a business opportunity for Fab Labs. They could, for example, offer user innovators to stress test their innovations. If approved by official experts, the product in return gets a Fab Lab seal, similar to the German "TÜV" certifications, handing of potential liability issues to Fab Labs. If a user innovation is not yet mature enough, they can give recommendations on product improvements so that, after some trial and error, a seal could be granted. The demand of such a service by user innovators and the potential importance of such a branding for end consumers should be examined in further research. With choice-based conjoint analysis, for example, not only the importance of such a branding but also the willingness to pay could be examined with potential consumers. A Fab City seal might have the potential to become a strong brand if it signals sustainability, local production, and assures users that no big companies, only user innovators profit from it. Analyzing the potential of this signaling effect is another interesting direction for further research.

## 13.4 Customer Adoption Barriers

Innovation diffusion, as defined by Rogers (2003), is the "(…) process by which an innovation is communicated through certain channels over time among the members of a social system." Diffusion in the context of Fab Labs refers to the aggregated adoption of digital product designs and their reproduction with the (open-source) production equipment available in the facilities.

Fast and wide diffusion processes require that innovations are useful to customers and represent a better alternative compared to existing products (Ram, 1987; Rogers, 2003). This creates a pro-change bias, meaning that consumers are open to change and have an interest in evaluating new products (Sheth, 1981). However, if consumers reject the innovation before really evaluating it, they will never fully realize its potential (Talke & Heidenreich, 2014). An innovation may have obvious advantages for its developers, yet potential customers initially tend to be less enthusiastic because the adoption of new products involves uncertainties (e.g., quality, reliability, safety) and often requires the customers to change their behavior. High perceived risks and adaptation costs are particularly prevalent in the case of high-tech novelties (Heidenreich & Handrich, 2015; Ram & Sheth, 1989). For example, the diffusion of green innovations is often sluggish. Products with a more favorable environmental impact often struggle to penetrate mainstream markets because their climate neutrality is often accompanied by deficits in performance which, in turn, forces the early adopters to change their usage behavior. For example, early models of electric vehicles involved a high cost in changed behavior as the maximum driving range with one battery load was very limited (Klein et al., 2020).

Ram und Sheth (1989) categorize the adoption barriers into two groups: functional (usage, value, risk) and psychological barriers (tradition, image), which are presented in Table 13.1.

**Table 13.1** Overview of adoption barriers

| | |
|---|---|
| Usage barrier: | • Not in line with current habits, routines, processes, or procedures |
| Value barrier: | • No significant added value, poor quality-to-price value |
| Risk barrier: | • Physical risk<br>– Safety issues<br>• Economic risk<br>– Too little value for money, too high implementation costs, unclear value loss of product<br>• Functional risk<br>– Low reliability, performance, quality<br>• Social risk<br>– Negative feedback from peers, negative reputational effects |
| Tradition barrier: | • Innovation requires a cultural change<br>• Incompatible with existing standards and norms |
| Image barrier: | • Simplistic negative perceptions of new technologies<br>• Stereotypic views of innovators |

In the following, we discuss potential functional barriers which are likely to be most relevant in the Fab City context.

**High Perceived Functional Risk** The perceived risk regarding the safety, reliability, and performance of products that are manufactured in Fab Labs is a key adoption barrier. Usually products are designed by firms, often established brand owners, that have built up a reliable reputation of generating high-quality solutions. If products are designed outside firms by individual professionals, hobbyists and amateurs, to be then produced in a rather unknown fabrication space, it is likely that potential adopters perceive a higher functional and economic risk. User innovations might be considered as amateurish and not tested extensively. In addition, potential customers can hardly evaluate the quality of the production process and quality control within Fab Labs. Some consumers might have more safety concerns about the statics of a chair they sit on than for a small play figure. Others, in contrast, are specifically afraid of the material of these small play figures as they have kids who might put them in their own mouths. As outlined in Sect. 13.3, these fears could be overcome with a trusted Fab Lab seal for risk-sensitive products in order to forestall potential consumer fears on safety, quality or performance.

**Low Relative Advantage** As most Fab Lab products will not be radical innovations, it is very likely that producers already offer a standardized alternative (e.g., drones). Therefore, a key mission for the Fab City Initiative is to highlight the unique selling points (USP) of locally manufactured products (e.g., customization, climate friendliness, "support your locals", etc.) and to target potential barriers that hinder consumers to adopt this specific product in a Fab Lab. Furthermore, research activities should focus on investigating which products would win the most from individual customization, as these are more likely to be products consumers would prefer to adopt in a Fab Lab.

**Misalignment with Current Usage Behavior** Although the exemplary outlined USPs can be classified as relative advantages compared to traditional products, they might trigger usage barriers. Consumers are used to buying their products online and in stores that are close by or in the city center. Buying products now in Fab Labs is, therefore, not in line with their current habits. A consumer might have never been in a Fab Lab before, might not know how to find one or, worst, might never have heard of the Fab Lab concept at all. For this reason, it is important to create general awareness about Fab Labs and how to find them. Thus, it is crucial to overcome potential inhibitions to visit these (subjectively) unfamiliar Fab Labs. This could be done by, for instance, making events that address a wide target group. Here, the first contact with a Fab Lab in order to build trust is more of interest and less that every participant goes home with a Fab Lab product. Moreover, city planners should examine the best locations for these Labs. It could, for instance, be beneficial to build them next to supermarkets as a visit would not change customers' daily routines too much.

Another usage barrier might be the as of yet rather complex software needed to operate machines or to customize the product. Although, end users might already be familiar with the concept of mass customization (Piller, 2004), the number of potential options could lead to an information overload; also both UI and UX are, currently, unsuitable for the masses. Therefore, building easy to use (standardized) software and toolkits is a major task for the Fab City initiative. Furthermore, showcasing typical Fab Lab products in Fab Labs could be beneficial to consumers for a better understanding of the outcome. In time, the offer of services like production and rework on request should be considered, so that less tech-savvy consumers only must come in to pick up the product or get it delivered to their homes. This service could be an interesting business model for Fab Cities.

## 13.5 Conclusion

For a significant impact on the environment, Fab Cities must get a critical mass of citizens on board. On the one hand, enough user innovators need to be convinced to share their replicable designs with the community and, on the other hand, enough end users need to adopt them.

Obviously, the first incentive that comes to mind is monetary compensation for designers to overcome the current diffusion shortfall. We find that voluntary payments for open-source hardware is a very promising field of research since, unlike with open-source software, (micro-)payments for materials as well as wear and tear take place anyway. This open-source-hardware phenomenon might lead to more frequent and higher tips for designers and could, therefore, be the decisive point for some user innovators to share their ideas or enhance diffusion efforts. At the same time, all ideas remain open-source while there should be no increased economic risk for end-users, as there is no obligation to tip anything with the mentioned participative pricing mechanisms.

Furthermore, we suggest that Fab Cities, as independent authorities, should consider establishing a seal of quality and anchor of trust that bundles legal rights. For instance, by supporting user innovators with legal matters, such as IP protection or liability. This could constitute a new business model for Fab Cities to generate revenue streams and, finally, become self-sufficient. Although consumers will have to pay some extra fees for these services, they might be necessary to overcome adoption barriers and, consequently, support the diffusion of user innovations. In this context, future research should investigate if these commercial and open models could work in parallel and if they could even benefit from each other. Consumers might wonder why some products have a Fab City seal, while others have not.

Finally, giving general advice on how to address potential value barriers is difficult, as it is mostly very product-specific. However, communicating the fundamental USPs of local production can be supportive (e.g., customization, climate friendliness, "support your locals", etc.). Maybe some direct comparisons of popular Fab Lab products to their commercial siblings in terms of cost, quality, carbon footprint, etc. could be promising marketing activities. For some products, the time factor could be another USP. Imagine needing a specific spare part for your dishwashing machine where delivery takes 10 days vs. just going to a Fab Lab and printing it there. Further research should investigate how frequent such cases are and may utilize this example for an influence on/of marketing.

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# Exploring Open-Source Software Ecosystems for Hardware Development

14

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## 14.1 Introduction

Innovative approaches to hardware design and production within the framework of Fab Cities and circular economies are relevant for policy makers. Understanding the synergy between open-source software and hardware is a first step in the realization of the potential of collaborative and co-developed approaches.

The popularity of Free/Libre and Open-Source Software (FLOSS) today is evident in the industry with web servers, frameworks, and tools powering the world (Ebert, 2008).

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Open-Source Hardware (OSH) is inspired by FLOSS; it is gaining traction with the Maker movement (Davies, 2017) and successes such as the Arduino, RepRap 3D Printers, and numerous other Open-Source Hardware Association (OSHWA) certified projects (OSHWA, 2023b). OSH is also gaining momentum in the spirit of knowledge dissemination with the CERN Open Hardware Initiative (CERN, 2023), Open Science Hardware communities (Anon, 2017) and by numerous other publicly funded initiatives.

The FLOSS ecosystem for hardware development is flourishing. Many OSH projects use libre software tools for development (Cadena et al., 2018; Collins et al., 2020); yet many OSH projects still rely on proprietary tools, locking-in hardware designers to closed platforms (Correa et al., 2017; Booeshaghi et al., 2019). Little attention is devoted to the importance of libre software ecosystems for OSH, as the openness of OSH often focuses on availability of the source but not the tools which are used to develop such hardware (Bonvoisin et al., 2017).

FLOSS for hardware development offers powerful tools compatible with Fab City manifesto values (Rimmer, 2021). In times of scarcity, waste, environmental impact (Lieder & Rashid, 2016; Santato & Alarco, 2022), issues with products such as planned obsolescence (Malinauskaite & Erdem, 2021), limited rights to repair (Hernandez et al., 2020), lack of privacy, and exploitable security in hardware (Young et al., 2019; Dawson et al., 2021), may put limits on the potential of a more sustainable society, as OSH could allow for less environmental impact through collaborative circular designs and less waste through longevity-oriented support for hardware. Policy makers should consider ways to guide the public, makers, and enterprises to use or design projects that are reusable and modular for circular economies. OSH, designed and developed with FLOSS tools, will allow anyone to contribute to the common good without the need for restrictive licensing. We believe that this circular-economy challenge may be supported by both OSH and a harmonious ecosystem of OSH and libre software.

In the context of Fab Cities and circular economies, this chapter explores two questions: (1) Why is OSH important? and (2) What are libre software ecosystems for hardware?

This chapter attempts to address these questions. We introduce OSH, discuss the drawbacks of proprietary hardware, describe the OSH market environment, highlight the potential of libre software for OSH, provide a model for describing software ecosystems, and apply the model to two popular applications in the OSH community: FreeCAD and KiCAD.

## 14.2 What Is OSH and Why Does It Matter?

### 14.2.1 OSH Background

The FLOSS movement inspired the OSH movement, and is generally traced back to the Free Software Foundation (FSF), the GNU Operating System (OS), MINIX and the Linux kernel (Raymond, 1999; Bretthauer, 2001; DeBrie & Goeschel, 2016).

OSH is defined by the OSHWA and DIN SPEC 3105-1 (Arndt et al., 2020; OSHWA, 2021) as physical artifacts whose designs are available publicly so that anyone can use, study, modify, replicate, and sell or distribute such hardware. OSH projects may be as simple as a bracket (Gaudio, 2023) or as complex as an open hardware architecture.

OSH has enabled hackerspaces, makerspaces, and other hardware enthusiast communities to tinker with hardware and popularize do-it-yourself (DIY) designs in various communication channels (Davies, 2017). However, communities are not yet aligned to what constitutes the source of such hardware projects (Bonvoisin et al., 2017) – a challenge which the DIN specification for OSH ought to address. The use of proprietary hardware is not without its drawbacks as there are numerous implications that may adversely affect users.

### 14.2.2 Proprietary Hardware Shortcomings

Proprietary hardware refers to physical artifacts that hold patents, copyrights, or other intellectual property rights that restrict the modification, production, or distribution of hardware. Hardware that holds restrictive terms puts limits on the freedom that users have to utilize such artifacts. OSH, as defined by licenses such as the CERN Open Hardware License (OHL) (Ayass & Serrano, 2012), may contain proprietary hardware as separate modules as long as the open parts of the hardware are available for study, reuse, modification, and distribution. However, in restrictive hardware designs, users and makers are unable to do either with such designs. These restrictions bring about similar shortcomings that exist in proprietary software.

For instance, inability to audit hardware has brought a new class of attacks on modern microprocessors in the Spectre and Meltdown incidents – flaws that have caused serious performance penalties (Prout et al., 2018). In contrast, open micro-architectures such as RISC-V may be able to support security research to mitigate side-channel attacks and improve hardware security (Gonzalez et al., 2019).

Another example is the way that Smart TVs of major vendors spy on users and pose security threats, as attackers may covertly gain control over devices (Michéle & Karpow, 2014). Smart TV users are unable to control their hardware, update or fix security flaws if manufacturer service periods expire or if device manufacturers terminate support of the firmware or provide hardware upgrades. These shortcomings may also exist in other proprietary hardware such as WiFi routers, Internet of Things (IoT) devices, printers, smart home devices, industrial control systems, surveillance cameras, medical devices, etc. …And highlight the importance of the OSH movement, where physical design transparency may support the mitigation of hard-to-find software exploitable hardware bugs, a major challenge for security specialists (Dessouky et al., 2019).

### 14.2.3 OSH in the Market

OSH is suitable for distribution in the market for economic gain, despite the possible misinterpretation of the 'Open' designation. OSH, besides 'open' access, also guarantees the same rights of distribution that proprietary hardware has. The CERN Open Hardware License (OHL) (Ayass & Serrano, 2012) and the OSH DIN SPEC 3105-1 (Bonvoisin et al., 2020) stipulate that OSH designs, based on open-source software definitions, state the requirements for licensing terms that grant users the fundamental rights to use, modify, share, and distribute hardware designs, including the distribution of physical artifacts for economic gain.

The success of Arduino and RepRap 3D printers demonstrate that OSH can be financially viable, even in highly competitive markets. OSH projects offer low barriers of entry, high customer loyalty (Li & Seering, 2019), high product differentiation (Hannig & Teich, 2021), and resilience against supply chain disruptions (Oberloier et al., 2022).

Despite the challenges of OSH business models, the economic impact of OSH may be quantified as in a study by the European Union (EU) that estimates the benefit between 65–95 billion Euros across all member states with a cost-benefit ratio slightly above 1:4 – where small and medium-sized enterprises (SMEs) are by far the most active group of contributors (European Commission, 2021). Similarly, the impact by specific OSH projects may also be quantified, such as that of a magnetic resonance imaging scanner that could save healthcare systems millions per year (Moritz et al., 2019).

### 14.2.4 Potential of Libre Software for OSH Development

OSH can bring numerous benefits that are essential to society, especially when combined with libre software. This combination may enable a widespread participation by anyone in the hardware design process (Boujut et al., 2019), concentration of resources from industrial users to improve libre software (Andersen-Gott et al., 2012), potential elimination of complex Computer-Aided Design (CAD) exchange format converters, improvement and longevity of hardware by compatibility-oriented design, reuse of components as hardware is designed with modularity in mind (Collins et al., 2020), and urban transformation with circularly-oriented design (Buxbaum-Conradi et al., 2022).

The importance of libre software for OSH may be overlooked. OSHWA (2023a) and DIN SPEC 3105-2 offer assessment schemes to publicly verify that a given OSH design complies with their requirements. Despite the importance of the use of open-source toolchains (as we describe in this chapter), neither assessment process takes libre software for OSH into account. OSHWA does not mention any criteria for the file formats and DIN SPEC 3105-1 only requires that files are provided in their "original editable file format and in an export format that can be processed by software that is generally accessible to the recipients" (Arndt et al., 2020). Similarly, licenses such as CERN OHL, do not stipulate the use of libre software for hardware development; terms are concerned about the intricacies of available components or external materials (Ayass & Serrano, 2012).

OSH designers may decide to release project source files (e.g. CAD designs, electronic schematics, engineering files, etc.) in proprietary formats. Modern OSH licenses may not enforce that project files are in formats compatible with libre software, as there is often no stipulation about distribution of original or derivative work in compatible file formats, or whether the file formats should also be open. The availability for collaboration and reproducibility becomes dependent upon users obtaining licenses of proprietary software. Issues such as privacy (Spiegel, 2013), security (Yile, 2016), cloud migration of the software (a form of planned obsolescence) are evident in commercial software as a service (Junk & Spannbauer, 2018). Challenges in security, privacy also exist in open-source software (Rotella, 2018), but project developers have more control (Wermke et al., 2022), software remains compatible (Lundell et al., 2017), and auditable (Cowan, 2003).

For many, libre software for OSH offers an attractive alternative to the expensive software license fees and to cloud platforms that can drastically change their terms of service so that they would become practically unusable for open-source development processes. As the design process often involves both mechanical and electronic components, libre software for mechanical design and circuit design are viable alternatives. Two major libre alternatives for mechanical design are OpenSCAD and FreeCAD, the latter of which is known for its support of constructive solid modeling, boundary representation modeling, and multiple 3D design methodologies. As for electronic design, LibrePCB, FreePCB, and Fritzing are some of the options available, but KiCAD has gained traction as a replacement of proprietary software such as Eagle, due to its community, continuous support, libraries and growing ecosystem.

## 14.3 Understanding Libre Software Ecosystems for Hardware

OSH designers and users may employ open-source software to (1) use the hardware or (2) to work on hardware projects. In terms of hardware usage (1), the Arduino IDE started as a fork of Wiring (Severance, 2014) and now possesses a rich library selection of supported microcontrollers and sensors. Similarly, OSH machine tools, such as 3D printers or laser cutters, may rely on libre software for generating GCode commands derived from files used in 3D printing such as Standard Tessellation Language (STL) (Prusa, 2023), or in files used in laser cutting and engraving, such as Scalable Vector Graphics (SVG) (Oster et al., 2011). Machine control at firmware level, for open digital fabrication machines may also use open firmware such as GRBL or Smoothie, for their operation (GRBL, 2023; The Smoothie Project, 2023).

Working on hardware projects (2) is complex. It depends on the type of hardware and the different stages in development of such physical artifacts. Design, planning, manufacturing, quality control and logistic activities (Siller et al., 2009; Anderl et al., 2018) also rely on different sets of software. Computer-based tools for Computer-Aided Design

(CAD), Computer-Aided Process Planning (CAPP), Production Planning and Control (PPC), Computer-Aided Manufacturing (CAM), Computer-Aided Quality Control (CAQC), and Computer-Aided Inventory Management Control (CAIMC) may use a collection of different software to achieve set objectives. In proprietary software, there is a high degree of integration in the product-to-end-user design process – hardware developers can interchangeably and harmoniously integrate the processes of mechanical design with electronic design automation and simulation pipelines in one suite of software. In libre software, the integration is less apparent, users may combine different software at each of the stages of hardware development – this combination of software is what we refer to as the ecosystem of libre software.

It would be an unfathomable task to classify and analyse all possible combinations of software to support all workflows in the development of OSH at every stage. Figure 14.1 illustrates how different software ecosystems may be needed at different stages of hardware development. $S = \{A_1 \ldots A_n\}$ represent all the FLOSS available, $E_1 \ldots E_n$ represent a subset of software ecosystems that are used for a particular activity in hardware projects. For instance, the design and development phase would employ the subset $E_1$ which could contain all necessary software for CAD/CAE development. Each of the phases, $E_i$, should also reflect the type of hardware developed, as artifacts vary in size, complexity and requirements. There may be other activities requiring different $E_i$ for the task.

Workflows vary depending on the stage of hardware development, with different tasks completed by different software ecosystems. In order to describe libre software ecosystems for hardware in practice, there is yet another distinction: the possibility of different workflows $W$ within each hardware design stage. If we consider $W_i = E_1 \ldots E_n$ as the different software ecosystems required for a development cycle of hardware, we can describe the different workflows for each of the tasks in OSH development. Figure 14.2 illustrates a simplified example of the workflow for the manufacturing of a 3D part. At each step in the 3D printing process, different libre software may be employed. When we combine the different workflows for 3D printing, laser cutting, and CNC Milling, as a simplification, a machine may be manufactured – such as a machine tool (e.g., Vise, Lathe) or a digital

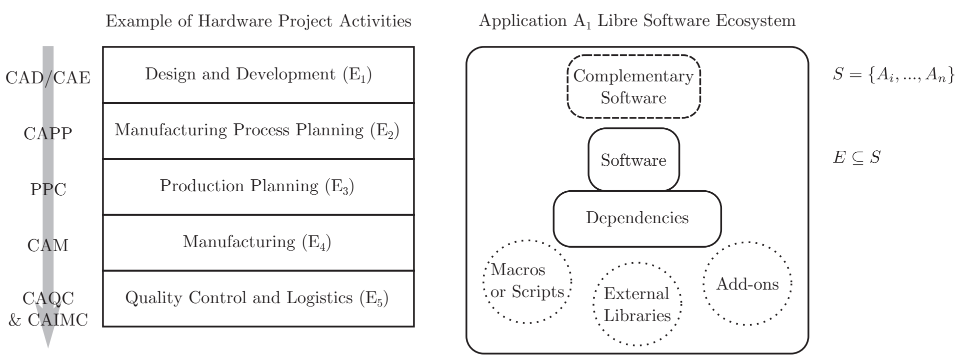


**Fig. 14.1** Libre software ecosystems for hardware development

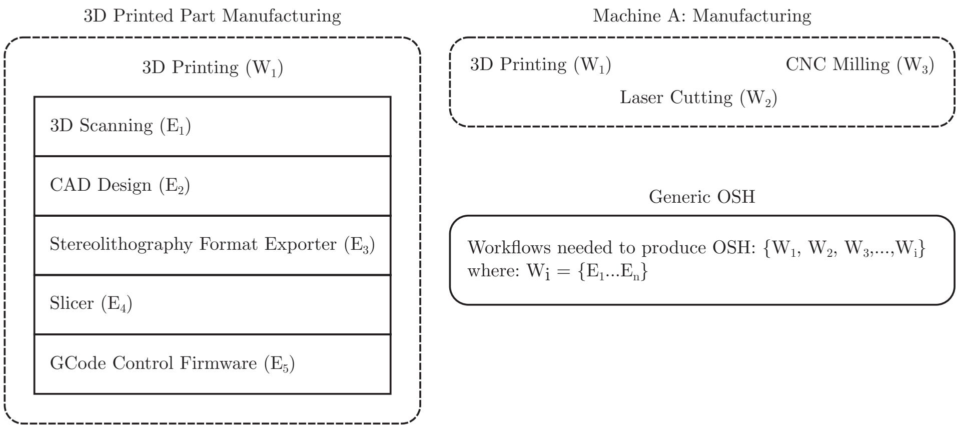


**Fig. 14.2** Manufacturing workflows for OSH production

fabrication machine (e.g., laser cutter, CNC mill, 3D printer). Manufacturing of OSH is a challenge and identifying workflows to produce such machines will support ideas such as the distributed manufacturing of OSH in open production plans (Mariscal-Melgar et al., 2022).

## 14.4 FLOSS Toolchains for Hardware: Examples

Figure 14.1 helps abstract internal ecosystems for software used in the different phases of hardware development. Let us consider the example of FreeCAD in Fig. 14.3, a parametric CAD application. On a lower layer of abstraction, there are different libraries and dependencies that make up the software. FreeCAD is based on a CAD kernel that provides the underlying structure and basic set of functions to create parametric shapes. The scene renderer displays them, the graphical user interface (GUI) provides a user interface and other dependencies deal with intricacies of the build-in features. Within the FreeCAD ecosystem, there are macros and scripts that expand software functionalities, external libraries in the form of generic 3D parts and add-on workbenches which may be installed separately. Additionally, there are complementary software, such as KiCAD, that, depending on the use case, may interact with FreeCAD for a particular task (e.g., generation of 3D models of circuit boards). All these components constitute FreeCAD's software ecosystem.

KiCAD is one of the complementary software that interacts with FreeCAD for the integration and development of OSH artifacts. KiCAD electronic design automation (EDA) tools facilitate the design of electrical schematics, the routing of printed circuit boards (PCBs) and the creation of Gerber files, a standard used in the industry for the manufacturing of PCBs. Figure 14.4 describes the electronic design ecosystem for KiCAD, the software is made of four major components: (1) the schematics editor, (2) the PCB editor, (3)

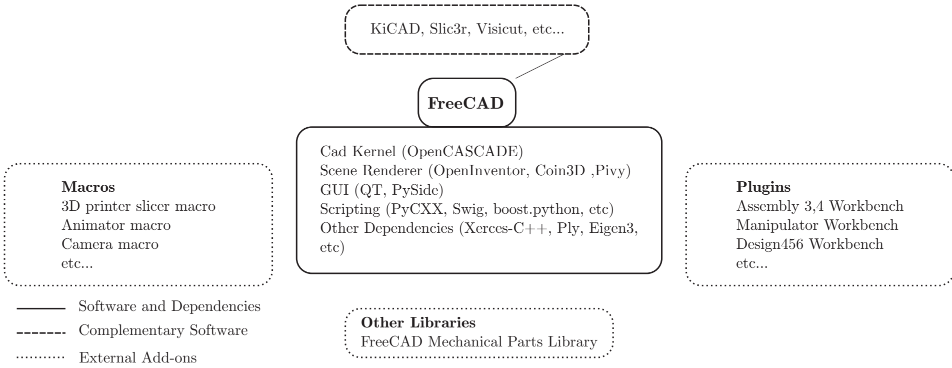


**Fig. 14.3** Simplified FreeCAD software ecosystem

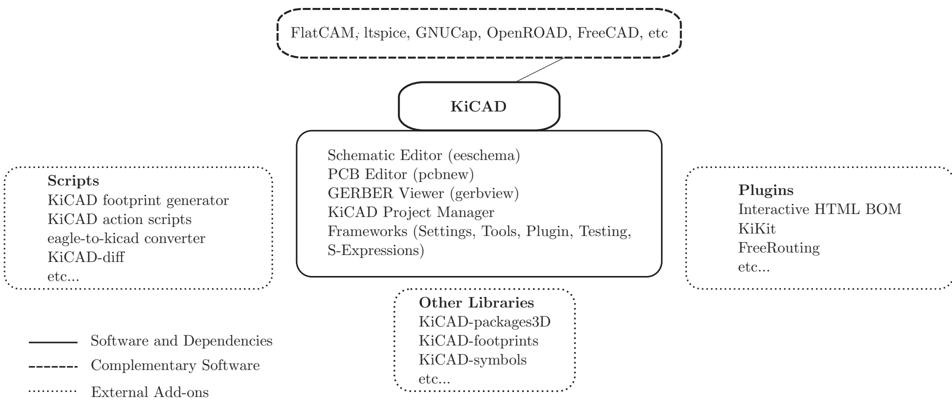


**Fig. 14.4** Simplified KiCAD software ecosystem

the GERBER Viewer and the (4) project manager. Each of these components depend on local sources and external libraries to provide the functionality of the KiCAD GUI. Complementary software are software tools that interact indirectly with KiCAD to provide more functionality. FlatCAM is useful in the production development stage of PCBs for milling, LTspice and GNUCap for simulation, OpenRoad for layout implementation and FreeCAD for the integration of the PCB physical representation into an overall OSH design.

## 14.5 Libre Software Toolchains: Discussion

These two examples of ecosystems should provide the reader with an overview of how varied and complex libre software ecosystems are and showcase the need that, for every new tooling, software developers should consider the ecosystem first – perhaps with a practical hardware-development-focused approach for the benefit of projects that rely on libre software tools to achieve their aims.

FreeCAD and KiCAD provide a lot of functionality, versatility, and modularity in their respective ecosystems. However, when compared to closed source solutions, such as the combo of commercial CAD/CAM/CAE tools, the ecosystem is less seamless. Commercial companies can leverage their position in the market with dependable development teams to target the industry and integrate solutions, all in a single package. However, those solutions are driven by the company's choices, as effective costs for features may rise as decisions may be purely market-driven, in contrast to constant availability of features in libre software. Proprietary software also suffers from data interchange problems if customers want to use other tools or import files in other formats, this practice allows for a more successful lock-in effect. We refer to this type of software as *competition-driven* software, as it relies on market-driven forces for survival (i.e., customers), whereas FLOSS alternatives may or may not rely on market forces for survival but also on collaboration and adoption for survival.

In *collaborative-driven* libre software, the focus is on the interoperability of software and solving of specific needs, while also providing tools for extensibility. Applications are modular, interchangeable, flexible to change and provide several options to users as exemplified by the rich ecosystems of FreeCAD and KiCAD in Sect. 14.4. The focus of FLOSS tools is that of *planned perpetuity* instead of *planned obsolescence*. Software is there to serve the users' needs, not to extract economic value from them.

There is a need to further improve libre software ecosystems, such as FreeCAD and KiCAD. Our examples demonstrate the complexity of these ecosystems, and the simplifications are there to guide the unfamiliar reader. Nevertheless, there is still a need for further work on a more effective integration of libre software, creating toolchains that provide users with experiences less fragmented and more harmonious for different workflows.

The OSH community, software developers, researchers, and policy makers could continue to support the creation of a more harmonious ecosystem of libre software for OSH. The next steps for the OSH community are to spread awareness of the vast ecosystem of libre software available for the creation of projects in open formats to ensure the projects' longevity. Software developers involved with libre software for hardware should continue their work, focusing on understanding practitioners' workflows and the toolchains needed for different applications, ranging from DIY and prototyping to industrial use-cases. Researchers could support the efforts by mapping out workflows and the different toolchains missing in different fields. Policy makers could support the OSH movement further by funding, as OSH adds value to the economy and aligns with climate, self-sufficiency, and circular economy objectives.

## 14.6 Concluding Remarks

This chapter provided an exploratory overview of OSH by describing the landscape of OSH and suggesting a way to understand and exemplify libre software ecosystems that are used to develop such hardware. FLOSS is usually financed through a combination of donations, grants, crowdfunding, dual licensing, commercial support, and particularly voluntary contributions. FLOSS toolchains for hardware are lacking, so the underlying message is that FLOSS for OSH is worth the support from policy makers (e.g., via dedicated funding). FLOSS for OSH development offers unique benefits to users and the economy. Despite some of the shortcomings of FLOSS tools for hardware, OSH designers should consider supporting FLOSS ecosystems by using them and providing feedback to developers.

Future research could focus on mapping different engineering workflows, to identify gaps in libre software. Additionally, it would be interesting to explore how leading commercial software companies may benefit from FLOSS, for instance, by adopting more common-standards, supporting universal CAD kernels, or improving file-format compatibility and interoperability.

In the context of circular economies, and new paradigms of production and consumption, it is necessary to re-think how society can design and produce products collaboratively with a focus on less waste and reuse. Is OSH one of the answers to the sustainability problem? Perhaps it is a combination of both, since libre software for open-source hardware in a more harmonious ecosystem.

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# Circular und Distributed Design im Kontext der Fab City

15

## Die Five Hamburg Principles of Circular Design

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## 15.1 Einführung: Multiple Krise und neue Design-Ansätze

Die gegenwärtige multiple Krise und die daraus entstehenden Herausforderungen für die Menschheit zeigen deutlicher als jemals zuvor, dass viele Systeme, die seit der Industrialisierung einem Teil der Menschheit Wohlstand und ein angenehmes Leben beschert haben, so in Zukunft nicht mehr funktionieren werden (Brand & Wissen, 2017; Bader et al., 2011). Pandemie und Krieg, Umweltbelastungen und Ressourcenverknappung, Klimakrise und das sechste große Artensterben sind Symptome einer Wirtschaftsweise, die natürliche Ressourcen vernichtet und Ökosysteme zerstört. Außerdem basiert sie auf Ausbeutung und Benachteiligung von schwächeren und ärmeren Bevölkerungsschichten und Regionen.

Die meisten Designenden sind heute noch Teil dieser Probleme, gestalten sie Produkte für die Überfluss- und Wegwerfgesellschaft und Kampagnen, die den Konsum anregen sollen.[1] Aber auch die Designbranche merkt mit zunehmendem Unbehagen, dass diese

[1] Was unseres Erachtens zum Teil auch an fehlender Expertise im systemischen Design und in quantitativer Bewertung von Umweltaspekten liegt.

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Strategien zur Überschreitung der „Planetaren Grenzen" (Rockström et al., 2009) führen. So fordern zahlreiche zivilgesellschaftliche Agierende (Fridays for Future, NGOs und andere) ein Umdenken von Unternehmen, Gestaltenden, Konsumierenden und in der Politik Tätige. Befördert wird ein solches Umdenken von aktuellen politischen Initiativen und Vorgaben (WEEE, RohS, REACH, Ecodesign Direktive, Circular Economy und Sustainable Product Regulation der EU, Lieferkettengesetz, Deforestation-Gesetz, Right to Repair etc.) (Tischner & Moser, 2015; European Commission, 2022).

Gefordert ist also die Gestaltung von Produkten, Dienstleistungen, Systemen, Kommunikation bzw. Information und Bildungsansätzen, um die Art und Weise, wie wir konsumieren und produzieren, hin zu größerer Nachhaltigkeit zu transformieren. Nachhaltigkeit wird hier im Sinne der Definition der Vereinten Nationen verstanden (World Commission on Environment and Development, 1987): Eine Lebens- und Wirtschaftsweise, die es der heutigen Weltbevölkerung erlaubt, ihre Bedürfnisse zu befriedigen, aber dabei kommenden Generationen ihre Lebenschancen nicht nimmt. Folgerichtig bedeutet nachhaltiges Design, dass Lösungen gestaltet werden, die gut für den Planeten und gut für die Menschen sind. Gleichzeitig muss es ökonomische Wertschöpfung für viele schaffen, nicht nur kurzfristigen Profit für wenige. Es geht also auch darum, den bisherigen Ansatz des ‚human-centered designs' – also des Nutzenden zentrierten Designs – auszuweiten auf ein ‚ecosystem-' oder ‚planet-oriented' Design. Leitend ist dabei die Einsicht, dass es ohne intakten Planeten und ein funktionierendes Ökosystem kein menschliches Leben geben kann und dass es ohne Menschen keine Ökonomie gibt. In dieser jüngeren ‚Nachhaltigkeitsdefinition 2.0' besteht also – anders als in früheren Definitionen – eine gewisse Hierarchie: Die drei Säulen Ökologie, Soziales und Ökonomie (planet, people, profit) stehen nicht mehr gleichwertig nebeneinander, sondern die Priorität muss heute darin liegen, zu verhindern, dass durch Klimawandel und andere menschengemachte Einflüsse die wichtigsten planetaren Grenzen überschritten werden (Rockström et al., 2009; Raworth, 2018).

Unter dem Oberbegriff des Sustainable Design oder Design für Nachhaltigkeit gibt es unterschiedliche Design-Ansätze, die hier ausschnittsweise zusammengefasst werden (Tischner & Moser, 2015):

- Ressourcen- und energieeffizientes Design, das auf minimalen Einsatz von Ressourcen und Energie abzielt.
- Circular und Cradle-to-Cradle Design, das sich dem Schließen von Materialkreisläufen widmet.
- Regeneratives und resilientes System-Design, das danach strebt, Systeme zu gestalten, die ebenso wie Ökosysteme regenerativ mit Energie und Ressourcen umgehen oder mit großer Resilienz auf Veränderungen und äußere Einflüsse reagieren können.
- Humanitäres und Social Design, das sich Aspekten der sozialen Gerechtigkeit und einem guten Zusammenleben der Menschen ohne Ausbeutung, Rassismus, Sexismus usw. widmet.

### 15.1.1 Circular Design im Kontext der Kreislaufwirtschaft

Im Folgenden wird der Fokus auf das Circular Design (Kreislaufdesign) gelegt, das im Kontext der Circular Economy (Kreislaufwirtschaft) verstanden werden muss: Im Jahr 1976 verabschiedete der US-Kongress den Resource Conservation and Recovery Act (US Congress, 1976), um Abfallvermeidung, Recycling und Ressourcenschonung zu fördern. So entstanden die drei Rs (Reduce, Reuse, Recycle) als Slogan, der diese Idee der Bevölkerung vermitteln sollte. In Deutschland wurde 1996 das Kreislaufwirtschafts- und Abfallgesetz beschlossen, das 2012 überarbeitet und aktualisiert wurde (KrW-/AbfG, 2012). Beide Gesetze wurden im Rahmen von Abfallvermeidungsansätzen entwickelt und denken das Problem ausgehend vom Abfall. Andere Ansätze, welche die Kreislaufwirtschaft in die Gestaltung von Produkten und Geschäftsmodellen integrieren, wurden bereits in den 1980er-Jahren von Walter Stahel vom Institut für Produktdauerforschung in der Schweiz entwickelt (Stahel, 1991). Er prägte auch den Begriff der „Performance Economy" (Stahel, 2010). Ende der 1990er-Jahre wurde das Cradle-to-Cradle Designprinzip von dem deutschen Chemiker Michael Braungart und dem amerikanischen Architekten William McDonough formuliert (McDonough & Braungart, 2002). Darauf aufbauend wurden Ansätze der Kreislaufwirtschaft weithin bekannt gemacht, unter anderem von der Ellen MacArthur Foundation[2] (Ellen MacArthur Foundation et al., 2019) und der Europäischen Kommission.[3]

Die Grundidee der Kreislaufwirtschaft und des Circular Designs ist es, möglichst alle Materialien, Komponenten und Produkte in unseren Produktions- und Konsumsystemen auf möglichst hohem Qualitätsniveau in Kreisläufen zu führen. Dabei werden technische und biologische Kreisläufe unterschieden. Das Ziel ist es, die Nutzung von aus der Natur entnommenen Rohstoffen und die Produktion von Abfällen so weit wie möglich zu verringern oder zu vermeiden. Typische Strategien des Circular Designs sind Rethink, Redesign, Reduce, Reuse, Repair, Remanufacture, Recycle (die ‚Rs') sowie De-polymerise, De-alloy, De-laminate, De-vulcanise, De-coat und De-construct (die ‚Ds') (vgl. Ellen MacArthur Foundation et al., 2019). Letztendlich geht es darum, Kreisläufe innerhalb einer Wertschöpfungskette zu schließen, aber auch die Stoffströme zwischen Wertschöpfungsketten durch Kooperation der beteiligten Agierenden zu verknüpfen. So kann ein industrielles Ökosystem erzeugt werden, in dem Materialien, Komponenten und Produkte immer weiter sinnvoll und ohne negative Effekte in technischen oder in biologischen Kreisläufen genutzt werden. Diese systemischen Prozesse können durch Digitalisierung unterstützt oder sogar ermöglicht werden. Zirkuläre Design Prinzipien sind folgerichtig zum Beispiel (Tischner & Moser, 2015; Medkova & Fifield, 2016; Kühr & Seidel, 2022):

- Design für die richtige Lebensdauer
- Nutzung von recyclingfähigen Materialien und von Rezyklaten
- Nutzung von unschädlichen Chemikalien und Rohstoffen

[2] Siehe https://ellenmacarthurfoundation.org.

[3] Siehe https://environment.ec.europa.eu/topics/circular-economy_en.

- Design für leichte Zerlegbarkeit und Neukonfiguration
- Standardisierung, Kompatibilität und Modularisierung von Bauteilen
- Design für Reparierbarkeit und leichte Wartung
- Anpassbares und aufrüstbares Design usw.

Eine Umstellung auf Kreislaufwirtschaft und -design können allein die globale Krise nicht lösen. Ihre Grenzen sind zunächst physikalischer Natur: den Hauptsätzen der Thermodynamik zufolge führt jeder materielle Transformationsprozess zu Entropie. Demnach können nicht alle Veränderungen der Gestalt von Produkten oder Materialien rückgängig gemacht werden und sie benötigen oft einen erhöhten Energiebedarf. Außerdem kann die Kreislaufwirtschaft den immer noch ansteigenden Konsum nicht ausgleichen. Kontraproduktiv sind auch die sogenannten Rebound-Effekte, die eintreten, wenn effizientere Güter häufiger oder mehr davon genutzt werden. Eine absolute Senkung des Ressourcenverbrauchs ist nötig, um die Planetaren Grenzen nicht zu überschreiten (de Man, 2022), jedoch wird durch die in Deutschland zurzeit gemessenen Recyclingraten keine Verringerung der absoluten Verbrauchswerte erreicht (Circular Economy Initiative Deutschland, 2021).

Zum anderen gibt es zahlreiche systemische und logistische Herausforderungen: Es fehlen häufig sowohl Systeme wie auch Technologien, um Produkte, Komponenten und Materialien auf effiziente Weise aus der Nachgebrauchsphase zurückzuholen und wieder sinnvoll einzusetzen. Langwierige und aufwändige Rücktransporte mit fossil betriebenen Transportmitteln führen zu zusätzlichen Umweltbelastungen. Solange die Energie für diese Redistributions- und Aufarbeitungsaktivitäten aus fossilen Quellen stammt, befeuern sie nach wie vor den Klimawandel. Schließlich gibt es noch viele ungelöste soziale Probleme. Zum Beispiel müssen geeignete Kooperationsnetzwerke von teils sehr verschiedenen Agierenden erst noch aufgebaut und gravierende Veränderungen auf dem Arbeitsmarkt bewältigt werden (wegfallende und hinzukommende Arbeitsplätze sowie die Qualität dieser Arbeit). Die soziale, ökologische und ökonomische Nachhaltigkeit muss also sorgfältig in die zirkulären Systeme hinein gestaltet werden und ist nicht per se gegeben.

### 15.1.2 Distributed Design in der Fab Lab- und Fab City-Bewegung

Parallel zur Entwicklung des Circular Designs ist das Konzept des Distributed Designs entstanden und hat vor allem in der Fab Lab- und Fab City-Bewegung Fuß gefasst (Gershenfeld, 2012). Distributed Design hat einen anderen Ausgangspunkt und demzufolge andere Schwerpunkte, die Circular Design in der Praxis ergänzen können. Im Zuge der weltweiten Verbreitung des Internets und des umfassenden Einzugs von Personal Computern in Wirtschaft, Verwaltung, Kunst und Sozialem Ende der 1990er-Jahre entwarf Neil Gershenfeld (Direktor des Center for Bits and Atoms, Massachusetts Institute of Technology – MIT) eine alternative Perspektive auf Technologieentwicklung und deren Folgen. Diese beschreibt er zusammen mit dem Kollegium des MIT folgendermaßen: „The next phase of the digital revolution will go beyond personal computation to personal fabrication.“ (Mikhak et al., 2002, o. S.) „At the heart of this idea is the belief that the most sustainable way to bring the deepest result of the digital revolution to developing communities is to enable them to participate in creating their own technological tools for finding solutions to their own problems.“ (ebd.) Die damalige Zukunftsvision ist 20 Jahre später Realität geworden. Heute gibt es rund 1500 Fab Labs in 90 Ländern. Diese soziotechnische Bewegung (vgl. Buxbaum-Conradi et al., 2018) folgt einem neuen Verständnis von Design, dem vier Elemente zugrunde liegen (s. Tab. 15.1).

Aufbauend auf diesen Merkmalen entstand das Konzept des Distributed Designs, das für die aufkommende Fab City-Bewegung konstitutiv werden sollte. Dieser Entstehungsprozess setzt Anfang der 2010er-Jahre mit dem wachsenden Bewusstsein für die globale ökologische Krise ein. In dieser Zeit entstand aus einer Zusammenarbeit von Neil Gershenfeld, Vincente Guallart, dem damaligen Direktor des Institut for Advanced Architecture Catalonia, Ort des ersten Fab Labs Europas sowie späteren Chefarchitekt der Stadtverwaltung Barcelonas und Xavier Trias (seinerzeit amtierenden Bürgermeister von Barcelona) die Idee einer sich selbst versorgenden Stadt (Guallart, 2014): die Fab City. Sie übersetzten die zuvor genannten Merkmale der Fab Lab-Bewegung in ein gemeinwohlorientiertes Verständnis von Design und Produktion und skalierten sie auf gesamtstädtischen Maßstab (Fab City Manifesto, 2018). Die Tab. 15.1 zeigt einen Vergleich der strukturierenden Merkmale der Fab Lab- mit der Fab City-Bewegung.

Ergänzt wurden die vier weiterentwickelten Merkmale durch den Anspruch auf Nachhaltigkeit und Ökologie sowie ein holistisches, regeneratives Modell von Konsum und Produktion im urbanen Kontext. Im Fokus steht eine Transformation von Städten im Sinne einer lokalen, zirkulären Wirtschaftsweise sowie die globale digitale Vernetzung solcher Städte untereinander (ebd.; Diez-Ladera et al., 2022).

**Tab. 15.1** Vergleich von strukturierenden Merkmalen der Fab Lab- und Fab City-Bewegung

| Merkmal | Fab Lab | Fab City |
|---|---|---|
| *Offenheit* | Offener Zugang zu digitalen Fertigungsmaschinen, Open source | Partizipation, Inklusion, Digital Commons |
| *Technologie* | Konvergenz der digitalen (Konzeption, CAD) und physischen (Herstellung, CAM) Arbeitsprozesse | Systematisierung des kooperativen Designs durch physische und digitale Infrastrukturen für eine lokale Produktion |
| *Gemeinschaft* | Bereitschaft zur Kooperation, Austausch und gegenseitiges Lernen (P2P) | Netzwerk von kooperierenden Städten, Bottom Up-Ansatz |
| *Innovation* | Experimentierfreude, DIY, community-orientierte Nutzung | Ein auf Menschen ausgerichtetes Verständnis von Technologie, Fokus auf sozialen Impact |

Bereits seit 2017 forscht und unterstützt das europäische Projekt Distributed Design Platform[4] entsprechende Initiativen. Im Sammelband ‚This is distributed Design' (Distributed Design Platform, 2021) fällt auf, dass deren Verständnis von Design sehr stark durch die Ziele der Fab Lab-Bewegung geprägt ist. Soziale Aspekte wie die Beteiligung von Bürgern, Empowerment von Communities, kollaborative Zusammenarbeit, eine verteilte und offene Produktionsweise sowie Do-It-Yourself stehen im Vordergrund. Der Anspruch auf ökologische Nachhaltigkeit wird klar benannt, in der Umsetzung wird allerdings vorwiegend auf Transportwege verwiesen, die aufgrund der lokalen Produktionsweise eingespart werden. Relevante ökologische Faktoren wie die Gewinnung und Anlieferung der zu verarbeiteten Rohmaterialien werden dagegen nur bedingt beachtet. Einen interessanten neuen Weg weisen in diesem Zusammenhang die Biolabs auf, in denen neue Materialien und Produkte durch biologische Prozesse generiert werden. Vielfach wird dabei ganz im Sinne des Circular Designs organischer Abfall genutzt.

Wie aus den vorherigen Abschnitten ersichtlich wird, müssen Produktgestaltung und Konsumverhalten nachhaltig transformiert werden. Neben den zuvor genannten politischen Verordnungen sowie den aufgezeigten wissenschaftlichen und konzeptionellen Ansätzen sind dafür aus unserer Sicht auch handlungsleitende Prinzipien wichtig, die die Ansätze von Circular und Distributed Design auf die Praxis von Designenden beziehen. Im Folgenden zeigen wir auf, wie im Rahmen des Circular Design Deep Dive fünf solcher Prinzipien erarbeitet wurden und stellen diese vor.

### 15.1.3 Die Five Hamburg Principles of Circular Design und der co-kreative Entstehungsprozess

Der Circular Design Deep Dive wurde maßgeblich vom Fab City Hamburg e.V. organisiert und fand im Design Zentrum Hamburg statt. Die dreitägige Konferenz bestand aus Vorträgen und Publikumsdiskussionen sowie fachlichen Inputs und vier co-kreativen Workshops.[5] Ziel der Workshops war es, gemeinsam mit Teilnehmenden und Experten der Konferenz Prinzipien für Circular Design zu erarbeiten, um vor allem Designende zu inspirieren, kreislaufgerechte Produkte zu entwerfen, zu produzieren und am Markt zu etablieren. Außerdem sollte intensive Gruppenarbeit die Wissensvermittlung zwischen den Teilnehmenden und ihre Vernetzung über die Konferenz hinaus fördern. Dieser Arbeitsprozess gliederte sich folgendermaßen:

Im Vorfeld haben die Organisierenden des Workshops 15 kurze Thesen zu Circular Design erarbeitet und mit den Experten auf digitalem Wege abgestimmt.

Die 15 Thesen wurden beim öffentlichen Auftakt der Konferenz dem Publikum präsentiert und erstes Feedback über eine digitale Plattform eingeholt.

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[4] Siehe https://distributeddesign.eu/about/.

[5] Siehe https://www.interfacerproject.eu/news/cddd-event/.

Thesen und Feedback sowie Inputs und Vorträge während der Konferenz dienten in den Workshops als Ausgangspunkte für den inhaltlichen Austausch der Teilnehmenden. Schrittweise wurden die ursprünglichen Thesen in zahlreichen Arbeitsgruppen diskutiert, vertieft, verdichtet und zu fünf Prinzipien weiterentwickelt. Für die Präsentation der Prinzipien erstellten die Teilnehmenden vier Plakate und ein Video.

Nach der Veranstaltung haben die Organisierenden die präsentierten Prinzipien noch einmal reflektiert und in Abstimmung mit interessierten Workshop-Teilnehmenden final überarbeitet.

Das Ergebnis dieses Prozesses sind die nun vorliegenden *Five Hamburg Principles of Circular Design*. Zusammenfassend kann gesagt werden, dass die fünf Prinzipien an bereits existierende Ansätze des Circular Designs anknüpfen und diese um Ideen aus dem Distributed Design ergänzen. Viele Vorträge und Diskussionen auf der Konferenz haben aber auch deutlich gemacht, dass zirkuläre Produkte und Vertriebswege nicht ausreichen, wenn Design eine nachhaltige Transformation von Wirtschaftssystemen unterstützen soll. Daher gehen die Prinzipien teilweise darüber hinaus und nehmen auch Aspekte mit in den Blick, die zum Etablieren kreislaufgerechter Produkte als Teil einer nachhaltigen Wirtschaftsweise relevant sind. Im Folgenden werden die fünf Prinzipien kurz dargestellt und erläutert.[6]

**1. Design für die Natur, Design aus der Natur: Alles ist vernetzt und auch Sie sind ein Teil des Ökosystems** Dieses Prinzip ist eine Synthese von verschiedenen Vorannahmen darüber, wie Design angesichts sozio-ökologischer Krisen ausgerichtet werden muss (siehe Abschn. 15.1) und soll die aus Sicht der Teilnehmenden notwendige Neuausrichtung der Disziplin von einem human-centered hin zu einem eco-system centered Design unterstützen.

**2. Messen Sie die Auswirkungen Ihres Designs: Etwa 80 % der Umweltauswirkungen eines Produkts werden während des Entwurfsprozesses bestimmt.** Dieses Prinzip soll deutlich machen, dass es aus Sicht der Teilnehmenden notwendig ist, potenzielle und reale Beiträge von neuen Designs strukturiert zu untersuchen, um fundierte Entscheidungen treffen zu können, ob und wie neue Produkte eine nachhaltige Transformation unterstützen (können). Dazu können wissenschaftliche Werkzeuge wie das Life Cycle Assessment genutzt werden.

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[6] Für die vollständigen Five Hamburg Principles of Circular Design siehe https://www.interfacerproject.eu/assets/news/cddd/CDDDPrinciples.pdf Die Prinzipien sind als Ergänzung zu anderen Arbeitshilfen zu verstehen, wie die Circular Design Rules des Institute of Design Research Vienna (siehe http://www.idrv.org/cdr/) oder Circular Design-Praktiken, die von der Ellen MacArthur Foundation erarbeitet wurden (siehe https://ellenmacarthurfoundation.org/introduction-to-circular-design/we-need-to-radically-rethink-how-we-design).

**3. Zusammenarbeit mittels frei zugänglicher Informationen ermöglicht Designlösungen für alle: Bauen Sie co-kreative Communities mit auf, indem Sie lokale Ökosysteme der Produktion mit Hilfe digitaler Werkzeuge und verteilter Designs weltweit vernetzen.** Dieses Prinzip verweist explizit auf die Möglichkeiten der verteilten und kooperativen Produktion der Fab Cities im Sinne des Distributed Designs (siehe Abschn. 15.1.2) und die Notwendigkeit von offenen, global vernetzten Communities, damit sich kreislaufgerechte Design-Lösungen besser durchsetzen können.

**4. Schaffen Sie authentische Bindungen durch ansprechende Geschichten: Heben Sie den Mehrwert von Kreislaufprodukten hervor, indem Sie die Geschichte und den Prozess dahinter so vermitteln, dass Inspiration und ein emotionaler Wert entstehen.** Dieses Prinzip unterstreicht die Bedeutung der Kommunikation in Bezug auf Circular Design und kreislaufgerechte Produkte. Designende sollten sich laut den Teilnehmenden vor allem um eine aufrichtige Vermittlung nachhaltiger Werte bemühen, die im Zusammenhang mit einem Produkt stehen und Verbrauchenden wenn möglich in diese Kommunikation mit einbeziehen. Nach Habermas könnte dies als *kommunikatives* Handeln verstanden werden. Im Gegensatz dazu stünde das Vortäuschen solcher Werte durch Marketing und Greenwashing als *strategisches* Handeln (siehe Abschn. 15.2).

**5. Setzen Sie sich für einen politischen Rahmen ein, der den Wettbewerb fairer macht: kreislaufgerechte Produkte können auf dem Markt nur konkurrieren, wenn Externalitäten berücksichtigt werden.** Dieses Prinzip problematisiert, dass externalisierte Kosten in vielen Fällen am freien Markt nicht abgebildet werden, weshalb eine politische Steuerung notwendig ist. In dieser Forderung spiegelt sich auch die Rolle der Fab City als zivilgesellschaftliche Mittlerin zwischen Politik, Wirtschaft und Verbrauchenden wider.

Dass aus den ursprünglich 15 Thesen diese fünf Prinzipien erarbeitet wurden, liegt in erster Linie an der Prozessdynamik der Workshops, den Inputs der Teilnehmenden und den von ihnen gefällten Entscheidungen. Im Arbeitsprozess konnten sie eigenes Wissen einbringen, mussten aber auch zahlreiche Aspekte vereinfachen und weglassen, um im gegebenen Zeitrahmen präsentable Ergebnisse zu produzieren. Trotz der damit verbundenen Unvollständigkeit gehen wir davon aus, dass Workshopergebnisse wie die Five Hamburg Principles of Circular Design eine nachhaltige Wirkung entfalten können. Dabei sind unseres Erachtens zwei Aspekte zentral: Sie müssen das Ergebnis eines offen angelegten und interdisziplinären Prozesses sein, der die Verständigung verschiedener Agierender fördert und sie müssen in der Praxis von Designenden weiterentwickelt und verbreitet werden. Dies führen wir im Folgenden aus und ziehen dafür das Konzept der Co-Creation heran.

## 15.2 Fab City als Handlungsumgebung für co-kreative Design-Prinzipien

In den vergangenen 20 Jahren hat sich nicht nur im Design eine Methode etabliert, mit der unter Einbeziehung möglichst vieler Perspektiven ein breiter Konsens in Bezug auf konkrete Lösungsansätze für aktuelle Probleme geschaffen werden kann: die Co-Creation.[7]

In seinem Buch zur „Theorie U“ stellt Scharmer (2014) Co-Creation als das zentrale Instrument zur Überwindung der bestehenden wirtschaftlichen, sozialen und kulturellen Störungen sowie persönlicher Reibungen vor. Dabei bezieht er sich unter anderem auf das Konzept des kommunikativen Handelns des Philosophen und Soziologen Jürgen Habermas (Habermas, 2019), das erstmals 1981 publiziert wurde und als ideengeschichtliche Grundlage des dialogischen und kooperierenden Prinzips der Co-Creation gesehen werden kann. In dem Buch legt Habermas dar, dass Vernunft weniger im einzelnen Subjekt als vielmehr in der kommunikativen Verständigung zwischen Subjekten entsteht. Dabei differenziert Habermas das *strategische* und das *kommunikative* Handeln. Nach Müller-Jentsch lässt sich dies wie folgt zusammenfassen: „Strategisches Handeln ist erfolgsorientiert; Sprechakte dienen hierbei als bloßes Mittel zur Zweck- bzw. Zielerreichung. Kommunikatives Handeln ist verständigungsorientiert; Sprechakte dienen der Erzeugung eines Einverständnisses auf der Grundlage kritisierbarer Geltungsansprüche.“ (Müller-Jentsch, 2002, S. 518). Co-kreative Workshops, wie sie im Rahmen des Circular Design Deep Dives durchgeführt wurden, können einen situativen Rahmen für kommunikatives Handeln bilden, wenn sie in Bezug auf den Inhalt der Ergebnisse offen angelegt sind, Teilnehmende mit verschiedenen Perspektiven ihre Sicht artikulieren sowie ihr Wissen einbringen können und so die gegenseitige Verständigung unter ihnen gefördert wird.

Damit solche Workshops zustande kommen und die in diesem Rahmen erarbeiteten Ergebnisse eine nachhaltige Wirkung entfalten können, ist aus unserer Sicht eine geeignete Handlungsumgebung erforderlich. Darin müssen unter anderem Ressourcen zur Durchführung von Workshops vorhaben sein (finanzielle Mittel, Räume etc.) sowie Netzwerke mit potenziellen Teilnehmenden, die über relevantes Wissen verfügen und bereit sind, es einzubringen. Darüber hinaus muss eine geeignete Handlungsumgebung Möglichkeiten bieten, dass Designende das co-kreierte Wissen erproben, weiterentwickeln und verbreiten

[7] Der Begriff stammt ursprünglich aus dem Marketing sowie den Wirtschaftswissenschaften und erfuhr durch die Veröffentlichung des Harvard Business Review Artikels, „Co-opting Customer Competence“ (Prahalad & Ramaswamy, 2000) eine große Resonanz. Daraufhin kam er zunehmend auch in anderen Bereichen zur Anwendung wie Transformationsprozesse, Soziale Innovation, Innovation in Unternehmen und Institutionen sowie der Gestaltung urbaner Räume (Tromp and van der Bijl-Brouwer 2016; Staudacher, 2021; Bason, 2010; Frow et al., 2015). Parallel dazu beeinflusste das Design Thinking als ein hybrider Ansatz für Innovation die Entwicklung von Design-Ideen und Produkten. Es basiert auf kreativen Design Methoden (Brainstorming, Prototyping, Iteration) und einer auf den Kunden ausgerichteten Prozessgestaltung (Brown, 2008).

können. Privatwirtschaftliche Unternehmen stellen dafür aus unserer Sicht in der Regel keine geeignete Handlungsumgebung dar – auch dann nicht, wenn sie mit co-kreativen Methoden arbeiten. Im Rahmen der unternehmerischen Produkt- und Innovationsentwicklung wird Co-Creation trotz ihres offenen, dialogischen Prinzips und des integrativen Charakters oftmals zu Zwecken strategischer Kommunikation eingesetzt, um privatwirtschaftliche Ziele zu erreichen, die bereits im Vorfeld definiert wurden.[8] Im Gegensatz dazu sollten Designende sich ihrer gesamtgesellschaftlichen Verantwortung bewusst werden, um zu einem neuen Verständnis ihrer Disziplin mittels verständigungsorientiertem Handeln zu gelangen, wobei verschiedene Perspektiven integriert und gemeinwohlorientierte Lösungsansätze erarbeitet werden.

Um diesen Prozess voranzutreiben, stellt die Fab City-Bewegung unseres Erachtens eine weitaus geeignetere Handlungsumgebung dar. Als zivilgesellschaftliche Bewegung verfolgt sie die Vermittlung von Wissen zu nachhaltigen Design-Lösungen innerhalb des Netzwerks sowie über die eigenen Kreise hinaus und die zugehörigen Labs ermöglichen es Designenden, neue Produktideen selbstbestimmt umzusetzen. Dadurch bietet sie geeignete Voraussetzungen zur Durchführung co-kreativer Workshops, die kommunikatives Handeln fördern sowie die Weiterentwicklung und Verbreitung von Workshop Ergebnissen in der Praxis. Außerdem ist die Fab City-Bewegung, wie im dritten Abschnitt dargelegt wurde, mittlerweile dabei, sich von ihrer Vorgängerin – der Fab Lab-Bewegung – zu emanzipieren.[9] Das ist aus unserer Sicht zu begrüßen, denn um angesichts heutiger sozioökologischer Krisen zukunftsfähige Lösungen zu entwickeln, greifen die ursprünglichen Zielsetzungen der Fab Labs zu kurz. Diese waren noch primär in sozio-technischen Herausforderungen der 2000er-Jahre verhaftet, wie dem steigenden Bedarf einer technologischen Literacy, einer zunehmenden digitalen Kluft und der Euphorie für das ubiquitäre Computing, ohne dass ökologische Aspekte eine zentrale Rolle spielten. Die Fab City-Bewegung kann daher zukunftsweisende Impulse liefern für Circular Design und die praktische Umsetzung einer Kreislaufwirtschaft. Dazu zählen vor allem der Fokus der Fab City-Bewegung auf lokale Produktionskreisläufe innerhalb von Städten und die globale Vernetzung von Städten durch digitale Technologien.

[8] Das Soziale Design dient dem Ziel, gesellschaftliches Gemeinwohl mit privatwirtschaftlichem Interesse zu vereinen (Tromp and van der Bijl-Brouwer, 2016) und nimmt gewissermaßen eine Vermittlungsrolle zwischen strategischer und kommunikativer Kommunikation im Kontext von Nachhaltigem Design ein.

[9] Ein weiteres Anzeichen für eine solche Emanzipation ist, dass im europäischen Projekt „Centrinno“ an sogenannten Fab City Hubs gearbeitet wird, bei denen Zirkularität als eines der fünf Kernziele definiert wurde. siehe http://www.centrinno.eu.

## 15.3 Fazit

Verständigungsorientierte Kommunikation dient dem Aushandeln von Normen und Werten. Angesichts der aktuellen ökologischen und sozialen Herausforderungen ist dies in Bezug auf eine nachhaltige Transformation heutiger Produktions- und Konsumweisen von großer Notwendigkeit. Insofern muss auch Design als Disziplin gesellschaftliche Verantwortung übernehmen und Antworten finden (Papanek, 1971), wie eine solche Transformation mittels Designs vorangetrieben werden kann. Die Konzepte des Circular und Distributed Designs geben dafür geeignete Lösungsansätze vor. In der Kombination von Design für zirkuläre Produkte und Systeme mit den verteilten Design- und Produktions-Ansätzen in Fab Labs und Fab Cities liegt ein großes Potenzial, um die Kreislaufwirtschaft dezentral und effizient zu gestalten.

Die Five Hamburg Principles of Circular Design sollen Designende unterstützen und inspirieren, kreislaufgerechte Produkte zu entwerfen (Prinzip eins und zwei), zu produzieren (Prinzip drei), am Markt zu etablieren (Prinzip vier) und sich marktwirtschaftlicher Hemmnisse bewusst zu werden (Prinzip fünf). Dabei sind die Prinzipien im Kontext einer geeigneten Handlungsumgebung – der Fab City-Bewegung – zu sehen. Die Prinzipien haben das Potenzial, aufgrund ihrer co-kreativ erarbeiteten und prägnanten Formulierung sowie ihrer lokalen Einbettung zunächst konkrete Wirkungen vor allem im Hamburger Teil der Fab City-Bewegung zu entfalten. Darauf aufbauend können sie eventuell auch im größeren Maßstab wahrgenommen werden und von den Prinzipien inspirierte Produkte auch außerhalb von Hamburg Beachtung finden. Insofern ließe sich in Analogie zum Circular und Distributed Design sagen, dass die Fab City-Bewegung eine geeignete Handlungsumgebung für nachhaltiges Design darstellen kann, denn sie unterstützt Designende dabei, co-kreatives Wissen und nachhaltige Produkte zu erschaffen, beides offen zirkulieren zu lassen und über die Fab City-Bewegung hinaus zu distribuieren.

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# Co-kreative Produktentwicklung für eine lokale und unternehmensübergreifende Produktion 16

## Neue Herausforderungen an die Arbeitsvorbereitung

Dominik Saubke und Pascal Krenz

## 16.1 Einleitung

Die Dynamisierung der Digitalisierung wirkt sich direkt auf die verschiedenen Aspekte der Produktentwicklung aus. Software-Tools zur effizienten und umfassenden Zusammenarbeit drängen auf den Markt und machen den Weg frei für neue Formen der Zusammenarbeit (Almeida et al., 2020). Menschen begegnen sich verstärkt im digitalen Raum, sowohl im privaten als auch im beruflichen Kontext (Amankwah-Amoah et al., 2021). Durch unsere digitalen Aktivitäten vermeiden wir Transport- und Individualverkehr, dies hat das Potenzial, einen Beitrag beim Erreichen der Klimaziele zu leisten und wird durch staatliche Förderprogramme (z. B. Work-at-Home, Steuervergünstigungen) bestärkt. (Reiffer et al., 2022)

Des Weiteren ist die Anfälligkeit der heutigen globalen, arbeitsteiligen Wertschöpfung nicht zuletzt durch große Störungen wie etwa die Covid-19-Pandemie, geschlossene Handelsknoten (Hafen von Singapur oder Shanghai) oder die Sperrung des Suez-Kanals durch das Containerschiff Ever-Given Teil des öffentlichen Diskurses geworden (Ivanov & Das, 2020). Der Produktionssektor muss resilienter werden, um zukünftigen Krisen besser begegnen zu können. Einen Teil der Produktion lokal am Ort des Bedarfs zu organisieren wird in vielen Unternehmen strategisch diskutiert (Krenz et al., 2022). Neuen Kooperationen und der engen Zusammenarbeit verschiedener Spezialisten in dynamischen und lokalen Produktionsnetzwerken wird das Potenzial zugeschrieben, die sich abzeichnende Lücke bei der Produktivität aufgrund mangelnder Vorteilseffekte (Größe, Skalen, etc.) und eines prognostizierten Effizienzverlustes gegenüber der globalen Massen-

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produktion verringern zu können. Die Produktion am Ort des Bedarfs ist ein bedeutender Faktor bei der Umsetzung des Fab City Gedankens und einer Transformation hin zur Circular Economy. Die bestehenden Produktionsstrukturen sollten zukünftig bei der Transformation stärker berücksichtigt werden. Dazu können die in hoher Zahl verfügbaren kleinen und mittleren Unternehmen (KMU) im urbanen Umfeld in die neuen digitalen Konzepte integriert werden.

Auch Produktentwicklung findet zunehmend im digitalen Raum statt (Lindemann, 2016). Dabei wird die kooperative Zusammenarbeit im Rahmen von Produktentwicklungsprojekten immer mehr zu einer neuen Form der Beschäftigung und des Auslebens individueller Interessen. Letzte Veröffentlichungen zeigen, dass die Entwicklung komplexer physischer Produkte in offenen und kollaborativen Gemeinschaften erfolgreich stattfinden kann (Hertwig et al., 2020). Ziel dieser Art von Co-Creation ist es, das Wissen der Vielen über klassische Unternehmensgrenzen hinweg zu bündeln, um Raum für interdisziplinäre und individuell geprägte Innovationen zu schaffen, die neue Märkte erschließen können (Schwab, 2017). Der Erfolg eines Artefakts am Markt bemisst sich an seiner Wettbewerbsfähigkeit (Umsetzbarkeit, wirtschaftliche Reproduzierbarkeit). Dies wird nach heutigem Verständnis im klassischen Produktionsunternehmen durch einen sinnvollen und frühzeitigen Wissensaustausch mit den relevanten Wissensträgern aller Fachdisziplinen eines Unternehmens sichergestellt (Aitamurto et al., 2015).

Die netzwerkübergreifende Wertschöpfung (Co-Production) (Redlich, 2010) erfordert ein genaueres Verständnis vom Zusammenwirken zwischen Unternehmensnetzwerken und Co-Creation Communities, um die Auswirkungen auf die Bewältigung der Aufgaben der Arbeitsvorbereitung (AV) und deren Teilbereiche, wie etwa der Planungsvorbereitung (PV), besser einschätzen und Herausforderungen erkennen zu können.

## 16.2 Theoretischer Hintergrund

### 16.2.1 Netzwerkcharakter von Co-Creation Communities in der Produktentwicklung

Co-Creation bietet ein hohes Potenzial zur Steigerung der Innovationskraft einer Gemeinschaft. Generell lässt sich Co-Creation als „gemeinsamer, kollaborativer, gleichzeitiger, kollegialer Prozess der Schaffung neuer materieller und symbolischer Werte“ (Galvagno & Dalli, 2014) beschreiben. Co-Creation lässt sich dabei durch verschiedene operative Prozesse umsetzen. Diese variieren in ihren Ausprägungen hinsichtlich struktureller, organisatorischer und strategischer Aspekte. Geläufige Prozessbeschreibungen sind Crowdsourcing, Customer Co-Creation, Open Innovation, User Innovation, Co-Design oder Crowd Engineering.

Die operativen Prozesse von Co-Creation können abstrahiert als eine Form der zweckgebundenen Wissensgenerierung interpretiert werden und können somit auf gewisse Bereiche der Produktentwicklung projiziert werden. Produktentwicklung wird im klassischen Kontext der Ingenieurswissenschaften unter anderem als wertschöpfende Aktivität verstanden, dessen Ergebnis ein Artefakt ist, welches „durch (seine) spezifischen Funktionen und Eigenschaften geeignet ist, konkrete Bedürfnisse (…) nutzbringend zu befriedigen" (Schmelzer, 1992). Mit den operativen Prozessen von Co-Creation lassen sich somit unterschiedliche Teilbereiche des Produktentwicklungsprozesses abbilden. In einem solchen Konstrukt werden Teile der bisherigen Akteure fokaler Unternehmen im Bereich der Produktentwicklung durch ein Netzwerk von Akteuren erweitert oder gar substituiert. Es entsteht eine neue Situation der Zusammenarbeit und des Zusammenwirkens zwischen den Wissensträgern, in der bestehende Prozesse nicht mehr oder nur unzulänglich funktionieren.

Co-Creation Communities (CCC) zeichnen sich durch verschiedene Charakteristika aus. In Tab. 16.1 sind die Netzwerk-Charakteristika (Mitglieder, Governance und

**Tab. 16.1** Mögliche operative Prozesse zur Umsetzung von Co-Creation

| Benennung & Quelle | Definition | Netzwerk (Netzwerkmitglieder, Governance, Maxime) |
|---|---|---|
| *Crowdsourcing* (Afuah & Tucci, 2012) | Mobilisierung einer großen Gruppe von Menschen zur Bewältigung einer Aufgabe (Ideenfindung, Dienstleistung, etc.) | – freie Partizipation, Einzelaktivität, Heterogenität<br>– Fokaler Agent, zentral<br>– Innovation, Partizipation, (Altruismus) |
| *Customer Co-Creation* (Ihl & Piller, 2010) | Integration von Kunden (Nutzenden) einer Unternehmensleistung in die Wertschöpfung; Kollaboration mit internen Akteuren. | – Kunden (Implizites Kundenwissen); Dyadische Zusammenarbeit vs. vernetzte kollaborierende Kunden<br>– Fokaler Agent, zentral<br>– Partizipation, (individueller Erfolg) |
| *Open Innovation* (Chesbrough, 2003) | Wissenstransfers zwischen Unternehmen im Bereich F&E (Innovationspotenzial, Marktpotenzial) | – Unternehmen, Start-Ups<br>– Kooperation zwischen Agenten, Interaktion<br>– Offenheit, Innovation |
| *User Innovation* (Von Hippel, 2009) | Systematische Nutzbarmachung von Innovation durch die Nutzenden am Ort der Produktimplementierung (z. B. durch spezielle Anforderungen). Gesteuerte Rückführung der Innovation. | – Nutzende (Kunden), Lead-User<br>– Fokaler Agent, gesteuert bis ungesteuert<br>– Diffusion, Innovation |
| *Co-Design (vgl. Partizipatives Design)* (Piller, 2005) | Beteiligung aller relevanten Akteure in dem Gestaltungsprozess einer Lösung zur besseren Erfüllung der Bedürfnisse. | – Unternehmen, Kunden, Entwickelnde, Nutzende, Designende<br>– Agenten, gesteuert<br>– Partizipation, Innovation |
| *Crowd-Engineering* (Hertwig et al., 2020) | Integration einer Vielzahl von externen Kräften (Crowd) in den unternehmensinternen Produktentwicklungsprozess (Kann über die Ideenentwicklung und Prototypen-Phase hinausgehen.) | – eher professionelle und erfahrene User, Gruppenaktivität<br>– Broker, hoher Koordinationsaufwand, Integration beim Agenten (i. d. R. Unternehmen)<br>– Offenheit, Partizipation |

Maxime) der gängigen operativen Prozesse von Co-Creation aufgelistet. Die Teilnehmenden in solchen Prozessen werden meist von intrinsischen und sozialen Motiven geleitet. Die Verschiedenartigkeit der Nutzengenerierung im Hinblick auf klassische Maxime der wirtschaftlichen Ordnung (Wirtschaftlichkeit, Wettbewerbsfähigkeit, etc.) muss dabei berücksichtigt werden. Die Koordinierung der Communities erfolgt dabei in der Regel durch einen externen Agenten, der mit einer Aufgabenstellung an die Menschen herantritt, um durch die kollektive Intelligenz ein besseres Ergebnis zu erzielen. Die Auswirkung der verschiedenen Charakteristika von Co-Creation Communities bei der Integration in den Produktentwicklungsprozess wird in Abschn. 16.4 genauer untersucht.

### 16.2.2 Netzwerkcharakter von Cross-Company-Production (CCP)

In der Einleitung wurden mögliche Vorteile der Verbindung von Co-Creation und unternehmensübergreifender Produktion beschrieben. Der Netzwerkcharakter von Co-Creation wurde im vorherigen Absatz erläutert, im Weiteren wird auf Formen unternehmensübergreifender Produktion eingegangen. Unternehmensübergreifende Produktionsnetzwerke können verschiedene Formen annehmen (Reichwald & Piller, 2009; Schuh & Wegehaupt, 2004). Die vernetzte Wertschöpfung kann nach Krenz in drei Grundtypen unterschieden werden, Typ I. die veränderungsfähige industrielle Wertschöpfung, Typ II. die kundenintegrierte industrielle Wertschöpfung und Typ III. die offene partizipative Wertschöpfung (Krenz, 2020). Die Grundtypen liefern eine genaue Beschreibung des Netzwerkscharakters und schaffen eine Basis für den Vergleich von Cross-Company-Production (CCP) und Co-Creation Communities (CCC).

> „In einer vernetzten Wertschöpfung erfolgt die Umsetzung der Prozesse der Produkterstellung […]durch die Zusammenarbeit autonomer, dislozierter Produzenten. […] Durch diese erweiterte Offenheit des Wertschöpfungssystems steigt die Anzahl, Verschiedenartigkeit, Autonomie und Dislozierung der potenziell, verfügbaren Wissensträger […] an.“ (Krenz, 2020)

Mit Cross-Company-Production (CCP) ist die unternehmensübergreifende Produktion in einem Netzwerk gemeint. Dabei gibt es keine starre Ausrichtung der Wertkette. Die Unternehmen übernehmen Teilschritte der Wertschöpfungsaufgabe je nach Bedarf und der eigenen aktuellen Produktionskapazitäten. Die Zusammenarbeit im Netzwerk ist daher ungerichtet. Die Wertkette wird entsprechend des Bedarfs organisiert, sie setzt sich bei jeder Anforderung neu zusammen. Die Bildung der Wertkette basiert dabei auf verschiedenen Faktoren, so kann der Ort der Anforderung, die Menge, das Artefakt und die Verfügbarkeit der unterschiedlichen potenziellen Unternehmen kurzfristig variieren. In Konsequenzen gibt es bei dieser Art der Wertschöpfung eine hohe Varianz der unternehmensübergreifenden Kooperation zwischen den Akteuren bei Erfüllung einer Produktionsaufgabe. Zudem muss von einer Verschiedenartigkeit der Produktionsmittel und Kompetenzen der Mitarbeiter ausgegangen werden. Die Cross-Company-Production (CCP) wird dem Typ

I. veränderungsfähige industrielle Wertschöpfung nach Krenz (Krenz, 2020) zugeordnet. Diese zeichnete sich durch folgende Charakteristika aus:

Die Netzwerkmitglieder sind autonom operierende Unternehmen mit einem hohen Grad der Spezialisierung. Sie sind horizontal und vertikal desintegriert. Die Unternehmenskooperation zielt vorwiegend auf die Erfüllung der Wertschöpfungsaufgabe ab. Der Kunde verlässt dabei seine Rolle als passiver Konsument nicht.

Die Governance folgt dezentralen Strukturen und erfordert einen höheren Koordinierungsaufwand. Es bedarf der Abstimmung zwischen den einzelnen Unternehmen hinsichtlich der übergeordneten Wertschöpfungsaufgabe. Die Unternehmen stimmen sich vorwiegend durch die Verwendung offener Standards (Prozess- und Produktstandards) ab. Es gibt auf Netzwerkebene keine hierarchische Koordination, insgesamt verfügt ein solches Netzwerk über eine hohe organisatorische Heterogenität.

Die Maxime der unternehmerischen Akteure sind Produktivität und Optimierung. Dies erfolgt konkret durch die Spezialisierung der eigenen Wertschöpfungsfähigkeit. So erfolgt eine Fokussierung hinsichtlich der Herstellungskosten und der Bereitstellungszeiten bei gleichbleibender Qualität.

Zusammenfassend führt dies auf Netzwerkebene zu einer hohen Anzahl verteilter Wissensträger bzw. Wissensressourcen. Die einzelnen Wissensträger (i. d. R. Unternehmen) sind durch einen hohen Grad an Autonomie geprägt und weisen ein hohes Maß an Heterogenität auf. Dies hat einen direkten Einfluss auf die Umsetzung der Wertschöpfungsaufgabe, da z. B. die konsequente Erfüllung der Aufgaben der Arbeitsvorbereitung (AV) von der Fähigkeit zum Aufbau einer gemeinsamen Wissensbasis abhängt (Ibert & Kujath, 2011).

### 16.2.3 Schnittstelle zwischen Entwicklung und Produktion: Arbeitsvorbereitung (AV) als Wissens-Aggregator im klassischen Unternehmen

In den vorherigen Abschnitten wurden die Begriffe der Co-Creation Communites (CCC) und der Cross-Company-Production (CCP) eingeführt, sowie deren Netzwerk-Charakter hergeleitet. Wie in Abschn. 16.1 skizziert, bietet die Kombination von CCP und CCC das Potenzial den Produktionssektor nachhaltiger zu gestalten. Im klassischen Produktionsprozess übernimmt die Arbeitsvorbereitung (AV) die Integration von Entwicklung und Produktion. Wie in Abb. 16.1 dargestellt ist die AV an der Schnittstelle angesiedelt. Die Kombination von CCP und CCC führt dazu, dass in einem neuen Produktionsprozess die Produktion durch CCP und die Entwicklung durch CCC abgebildet wird. Ein Zusammenwirken von CCP und CCC betrifft damit besonders das Aufgabenfeld der AV, denn die generelle Zuteilung und auch Erfüllung der Aufgaben wird erschwert, nicht zuletzt durch den unterschiedlichen Netzwerkcharakter. Dabei werden mehr als 15 % der produktbezogenen Kosten bereits vor Beginn der Produktion im Spannungsfeld arbeitsvorbereitungsbezogener

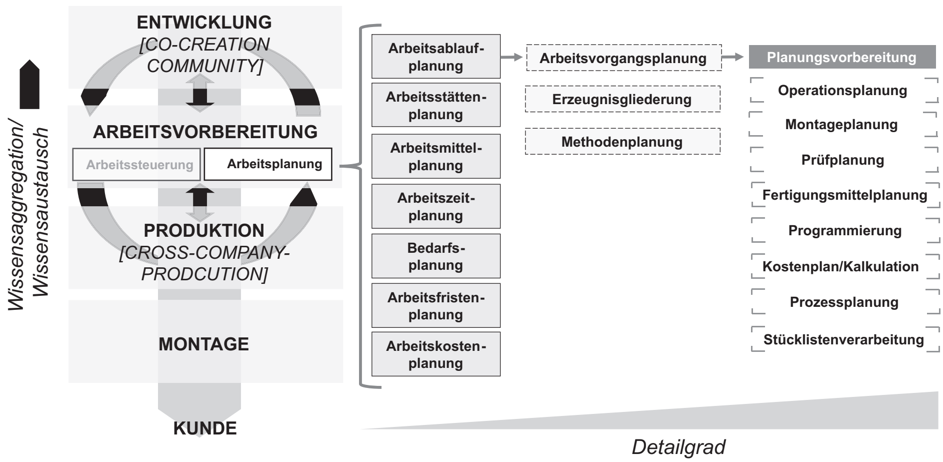


**Abb. 16.1** Aufgaben der Arbeitsvorbereitung als Schnittstelle zwischen Entwicklung und Produktion

Tätigkeiten festgelegt. Es ist damit hinter der Konstruktion die höchste kostenrelevante Position im Entwicklungszyklus (Eversheim, 2002). Die Verbindung von Co-Creation Communites (CCC) und Cross-Company-Production (CCP) bietet auf vielen Ebenen Potenzial für eine Steigerung der Produktivität, allerdings stellt sie auch die Arbeitsvorbereitung (AV) vor neue Herausforderungen. Diese agiert klassischerweise langfristig auf einer hohen organisatorischen Ebene im Unternehmen, deren Strukturen fest verankert sind. Anders als bei kurzen immer wiederkehrenden, vielfältigen und parallel ablaufenden Produktentwicklungsprozessen nimmt die AV zusätzlich die Rolle eines Wissens-Aggregators ein. Das klassische Aufgabenfeld der Arbeitsvorbereitung verbindet im Unternehmen die einzelnen Teilbereiche. Zudem übernimmt die AV in ihrer Hauptaufgabe eine Brückenfunktion zwischen Produktion und Konstruktion ein. Um die Wettbewerbsfähigkeit eines Unternehmens langfristig zu erhalten muss im heutigen Spannungsfeld ständig steigender Anforderungen an Qualität, vielfältigen und komplexen Herstellungsverfahren sowie niedrigeren Herstellungszeiten die Erfüllung der dort beschriebenen klassischen Aufgaben konsequent gewährleistet werden (Bauernhansl, 2020). Der abteilungsübergreifende Wissensaustausch kann dabei als eine der zentralen Aspekte interpretiert werden.

Das Aufgabenfeld der Planungsvorbereitung ist im heutigen Verständnis nach Eversheim wie folgt zu verstehen:

> „Die aus der Konstruktion stammenden Informationen werden hinsichtlich der vorliegenden Aufgabe, wie z. B. ihrer Fertigungs- und Montagegerechtheit, und hinsichtlich ihrer Vollständigkeit überprüft. Gleichzeitig werden präventive Maßnahmen zur Qualitätsverbesserung der Konstruktionsergebnisse durchgeführt, wie die Konstruktionsberatung oder die Ausarbeitung von Konstruktionsempfehlungen." (Eversheim, 2002)

Darunter fallen viele Aufgaben in den Bereich des Wissensaustauschs zwischen der Produktion und Entwicklung. Die Informationsbereitstellung durch die Planungsvorbereitung (PV) setzt dabei eine strukturierte Aufbereitung von Wissen voraus, um bei späteren Entwicklungsprojekten die konstruktionsbegleitende Beratung in einer qualitativ hochwertigen Form zu gewährleisten. Die Aufgaben müssen daher als kontinuierliche Prozesse verstanden werden und können wie folgt kategorisiert werden:

- Prüfung auf Vollständigkeit
- Erfüllung der Anforderungen an die technische Dokumentation (DIN)
- Prüfung einer fertigungs- und montagegerechten Konstruktion
- Beratung der Entwicklung
- Wiederverwendung vorhandenen Wissens
- präventive Maßnahmen zur Qualitätsverbesserung

Die Aufgaben lassen daher eine Unterscheidung zwischen konstruktionsorientieren und arbeitsplanungsorientierten Aufgaben zu. Der organisationseinheitenübergreifende Wissensaustausch (Integration) stellt dabei die Hauptaufgabe dar (Bauernhansl, 2020; Eversheim, 2002)

## 16.3 Ansatz und Vorgehensweise

Auf der einen Seite muss der Produktionssektor resilienter und nachhaltiger werden, um auf die gegenwärtigen Krisen angemessen zu reagieren. Auf der anderen Seite muss die Produktentwicklung in vielen Bereichen immer schneller werden, um auf die steigenden Anforderungen der immer anspruchsvolleren Nutzenden eingehen zu können. Diese fordern eine zunehmend höhere Individualisierbarkeit, eine Konsumerlebnis und Partizipation. Eine Kombination dieser beiden Entwicklungstrends und die damit einhergehende Verbindung der ihnen innewohnenden Vorteile wird weiter an Relevanz gewinnen. Co-Creation bringt die notwendigen Vorteile mit sich, die es braucht, um auf die wachsenden Marktanforderungen und deren unmittelbare Auswirkung auf moderne Produktentwicklungen reagieren zu können (Redlich et al., 2019).

Das Zusammenwirken der beiden verschiedenartigen Netzwerktypen, CCP und CCC führt zwangsläufig zu neuen Herausforderungen. Es stellt sich also die Frage, welche Herausforderungen entstehen, beim Zusammenwirken von CCP und CCC, bei der Erfüllung der klassischen Aufgaben der Arbeitsvorbereitung (AV) und damit auch der Planungsvorbereitung (PV) und wie sie aus Sicht der industriellen Praxis aufgelöst werden können.

Im Folgenden werden zur Beantwortung dieser Frage die zuvor herausgearbeiteten Netzwerk-Charakteristika von CCC und CCP gegenübergestellt und deren Zusammenwirken analysiert.

## 16.4 Ergebnisse

### 16.4.1 Die Komplexität des Zusammenwirkens von Co-Creation Communities (CCC) und Cross-Company-Production (CCP)

Das Zusammenwirken von Co-Creation Communities (CCC) und Cross-Company-Production (CCP) führt durch die Verschiedenartigkeit beider Netzwerke zu einer hohen Komplexität bei der Strukturierung der Zusammenarbeit. Die Arbeitsvorbereitung (AV) und Planungsvorbereitung (PV) stellen eine Integrationsmaßnahme dar, die das Zusammenwirken der beiden Bereiche optimieren soll. Die Integration beider Ansätze (CCC und CCP) ist aber sehr schwierig, weil die Wissensarbeit in beiden Ansätzen unterschiedlich funktioniert und eine sehr unterschiedliche Ausprägung der Netzwerke vorliegt. Co-Creation kann durch verschiedene operative Prozesse umgesetzt werden, daher nimmt auch die CCC zahlreiche unterschiedliche Formen und Ausprägungen an.

Im Weiteren wird das Verständnis über potenzielle Konflikte beim Zusammenwirken von CCC und CCP in Hinblick auf folgende operative Prozesse von Co-Creation vertieft: Customer Co-Creation, Co-Design und Crowd Engineering. Damit soll ein besseres Verständnis geschaffen werden, um ein solches Wertschöpfungssystem gestalten und umsetzen zu können. In Tab. 16.2 sind die Netzwerk-Eigenschaften aufgeführt.

Die **Netzwerk-Mitglieder** der CCC wirken freiwillig im Co-Creation Prozess mit und können unterschiedlichste Hintergründe haben. Bei Formen des Co-Designs können auch Unternehmen (z. B. Design-Agenturen oder Büros) in die Rolle eines Netzwerk-Mitglieds treten. Weiter ist vor allem der Crowd-Engineering Prozess hervorzuheben, bei dem es einer höheren Professionalität bedarf, um die Wertschöpfungsaufgabe im Entwicklungsprozess zu erfüllen. Insgesamt weist das Netzwerk ein hohes Maß an Heterogenität auf und besteht unter Umständen aus sehr vielen Akteuren. Um eine solche Community

**Tab. 16.2** Ausprägungen von Co-Creation-Communities und Cross-Company-Production

| | Cross-Company-Production | Co-Creation Communities |
|---|---|---|
| Netzwerk-Mitglieder | – autonom operierende Unternehmen<br>– hoher Grad der Spezialisierung<br>– horizontal und vertikal desintegriert (Wertkette) | – freie Partizipation<br>– Heterogenität<br>– eher professionelle und erfahrene User<br>– Einzelaktivität – Gruppenaktivität |
| Netzwerk – Governance | – dezentrale Strukturen<br>– hoher Koordinierungsaufwand<br>– offene Standards<br>– keine hierarchische Koordination auf Netzwerkebene | – fokaler Agent, zentral<br>– Agenten gesteuert<br>– Broker, hoher Koordinationsaufwand, Integration beim Agenten (i. d. R. Unternehmen) |
| Netzwerk – Maxime | – Produktivität<br>– Optimierung | – Innovation<br>– Offenheit<br>– Partizipation<br>– (Altruismus) |

aufzubauen und Aktivität zu fördern, wird eine entsprechende Motivation durch das CCP-Netzwerk erforderlich. Das CCP-Netzwerk besteht andererseits aus autonom operierenden Unternehmen, deren Beteiligung an der Wertschöpfungsaufgabe sich bedingt durch die eigene Spezialisierung nur auf Teilaspekte bezieht. Es muss daher davon ausgegangen werden, dass ein einzelnes Unternehmen des CCP – Netzwerks nur bedingt eine Leitfunktion bei der Motivation der CCC übernehmen wird. Dies wird verstärkt, da jedes Entwicklungsprojekt langfristig Ressourcen (Geld, Mitarbeiter, etc.) des Unternehmens bindet und ein Engagement ohne gesichertes Auskommen für die Unternehmen zu einem höheren Risiko führt. Das Risiko wird verstärkt, da das Ergebnis dem gesamten Netzwerk zur Verfügung steht. Zudem sind die Entwicklungstätigkeiten in einem solchen Gesamtsystem vielfältig, denn einzelne Entwicklungstätigkeiten beziehen sich jeweils nur auf einen ganz kleinen Teil der Produzenten. Dies beeinflusst auch die Betreuung der CCC-Aufgabe durch die zuständigen CCP-Mitglieder. Die horizontale und vertikale Desintegration innerhalb des CCP-Netzwerks hemmt zudem den Wissensaustausch und die konkrete Übernahme von Aufgaben bei einem Entwicklungsprojekt, das viele verschiedene spezialisierte Unternehmen umfasst.

Im Hinblick auf die **Netzwerk-Governance** zeichnen sich die beiden Netzwerke durch verschiedene Ausprägungen aus. Das CCP-Netzwerk hat keine hierarchische Koordination, sondern beruht auf reiner Kooperation. Die Unternehmen sind horizontal und vertikal desintegriert, die Abstimmung erfolgt auf Basis von Standards. Diese Ausrichtung steht im Gegensatz zur CCC, welche je nach operativem Prozess eine zentrale Steuerung durch einen oder mehrere Agenten voraussetzt. Im Falle des Crowd-Engineerings wird von einem zentralen Broker ausgegangen, der die Koordination der Entwicklungsprojekte übernimmt und die Integration in das jeweilige verantwortliche Unternehmen lenkt. Eine Steuerung durch ein einzelnes Unternehmen kann so umgangen werden. Es bedarf dafür einer gesteigerten Offenheit, um die entsprechende Information, z. B. sensible Inhalte zu Entwicklungsprojekten, mit einem Intermediär (Broker) auszutauschen.

Sowohl das CCP als auch die CCC sind nach deutlich unterschiedlichen **Netzwerk-Maximen** ausgerichtet. Für die beteiligten Unternehmen im CCP-Netzwerk ist das übergeordnete Ziel die Steigerung der eigenen Produktivität und damit der wirtschaftliche Erfolg. Bei CCP funktioniert die Wissensarbeit im Netzwerk über Formalisierung und Standardisierung. Dies schafft Effizienz im Sinne einer sicheren Kopplung von Spezialistenwissen. Die Akteure wollen ihr Wissen schützen, daher kombinieren sie ihr Wissen über Standards. Eine offene Kommunikation wird eher als negativ angesehen, weil es unter Umständen auch zu Ineffizienz (z. B. redundante Kommunikation) führen kann und die Gefahr zum Abfluss von wettbewerbsrelevantem Wissen besteht. Dies kann mit den Maximen der CCC im Konflikt stehen, die unter Offenheit auch das Teilen von Informationen mit Akteuren außerhalb des Gesamtsystems verstehen. Auch altruistische Tendenzen der CCC stehen im Konflikt mit einer rein wirtschaftlichen geprägten Optimierung auf Seiten des CCP-Netzwerks. Dagegen lässt sich anführen, dass das Gesamtsystem nach Innovation strebt und so ein gemeinsamer Treiber des Zusammenwirkens identifiziert ist.

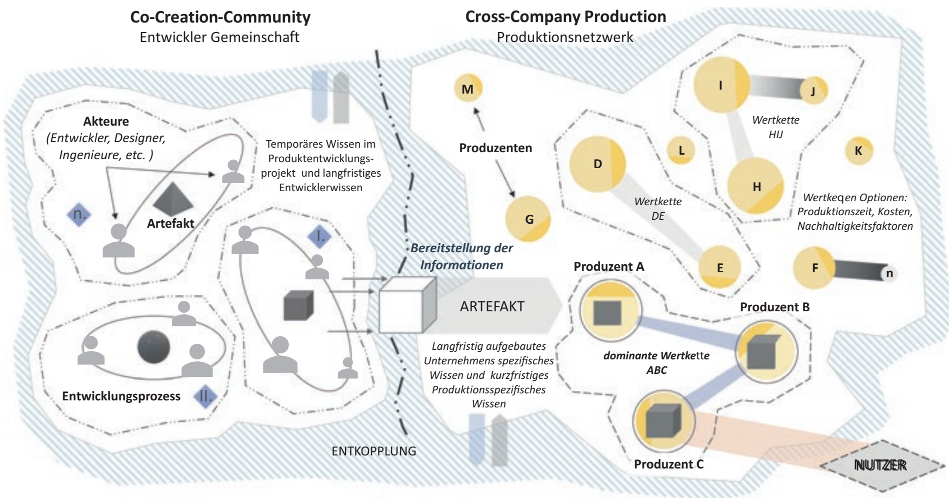


**Abb. 16.2** Zusammenwirken von Co-Creation-Communities und Cross-Company-Production

Die Gegenüberstellung zeigt, dass bei einer Produktentwicklung durch CCC die notwendige Integration und Interaktion mit den relevanten Unternehmen des CCP-Netzwerks sich herausfordernd gestaltet. Der Wertschöpfungsprozess beim Zusammenwirken von CCC und CCP wird in Abb. 16.2 dargestellt. Die unterschiedlichen Ausprägungen in den Bereichen der Netzwerk-Mitglieder, der Netzwerk-Governance und der Netzwerk-Maxime beider Teilsysteme führen in der Konsequenz zu einer Entkopplung von Produktion und Entwicklung. Die Entkopplung verhindert den freien Wissensaustausch und führt zu einer geringeren Produktivität, höheren Kosten und einer geringeren Produzierbarkeit der entwickelten Artefakte. Der Entkopplung kann mit einer Optimierung und Neugestaltung des Wissensaustausches begegnet werden.

### 16.4.2 Herausforderungen im Spannungsfeld zwischen Co-Creation Communities und Cross-Company-Production im Kontext der Arbeitsvorbereitung und Planungsvorbereitung

Die beschriebenen Co-Creation Communities (CCC) bieten das Potenzial für neue Innovationen, kürzeres Time-to-Market und einer Nutzenden-orientierten Produktentwicklung. Im Zusammenwirken mit einem Cross-Company-Production (CCP) Netzwerk kann dies weitere Möglichkeiten zur Optimierung und Effizienzsteigerung bedeuten. Die Gegenüberstellung der beiden Netzwerke hat gezeigt, welche Herausforderungen dabei entstehen, vor allem im Wissensaustausch und bei der Steuerung von Entwicklungsaktivitäten. Die zuvor beschriebene Entkopplung zwischen Produktion und Entwicklung geht mit der Konsequenz einher, dass einige der klassischen Aufgaben der Arbeitsvorbereitung (AV) und Planungsvorbereitung nicht erfüllt werden können und neugestaltet werden müssen.

Weiter sind in einem solchen Netzwerk in der Regel mehrere Mitglieder gleichzeitig beteiligt. Die relevanten Informationen für die spätere Produktion eines solchen Teilaspekts des späteren Artefakts müssen also zwischen den Beteiligten abgestimmt und nachvollziehbar gespeichert werden. Hier kommt erschwerend hinzu, dass von redundanten Produktionskapazitäten ausgegangen werden muss. Dies führt in der Praxis dazu, dass unterschiedliche Unternehmen die gleichen Herstellungsverfahren mit unterschiedlichen Fertigungsmaschinen abbilden. Die Unternehmen benötigten zur Umsetzung der Wertschöpfungsaufgabe unter Umständen stark abweichende Informationen. Die Beratung durch ein einzelnes Unternehmen kann daher nur bedingt zielführend sein. Generell führt dieser Umstand zu einer gesteigerten Anforderung an die technische Dokumentation, besonders im Hinblick auf Fertigungs- und Montageverfahren. Eine weitere Herausforderung ist die Verfügbarkeit von Ressourcen zur Beratung und ggf. zur Abstimmung zwischen den zuvor genannten potenziellen Unternehmen, die eine spätere Wertschöpfungsaufgabe übernehmen sollen. Dies führt zwangsläufig zu der Gefahr von Mehrdeutigkeiten in der technischen Dokumentation, um der Vielfältigkeit der Produktionsmöglichkeiten gerecht zu werden. Genauso muss beachtet werden, dass es eine Wechselwirkung zwischen einzelnen Bauteilen gibt, die später von unterschiedlichen Spezialisten im Netzwerk umgesetzt werden. Sollen solche Wechselwirkungen ausreichend beachtet werden, hemmt dies die Parallelisierung von Entwicklungsaktivitäten. Besonders der langfristige Charakter der Aufgaben der Planungsvorbereitung (PV) stellt das Gesamtsystem vor neue Herausforderungen. Die einzelnen Unternehmen des CCP-Netzwerks können die eigene Partizipation im Netzwerk nur schwer voraussagen.

Die AV als übergeordnete Instanz der PV muss aber als Wissensaggregator verstanden werden, der langfristig bei allen, auch parallel ablaufenden, Entwicklungsaufgaben die notwendigen Informationen zur richtigen Zeit bereitstellt. Dabei geht es um die systematische Aufbereitung von Wissen zur Wiederverwendung, denn nur so kann die Produktivität gesteigert und eine hohe Produzierbarkeit der entwickelten Artefakte herbeigeführt werden. Es gilt zudem, präventive Maßnahmen zur Qualitätsverbesserung frühzeitig in den Entwicklungsprozess einzusteuern.

Beides funktioniert durch die Entkopplung nicht mehr, die Aufgaben der PP können nicht klar zugeordnet werden. Die Aufgaben und Anforderungen an die Koordinierungsmechanismen müssen daher neu durchdacht werden. Während Eversheim noch zwischen einer kundenanonymen und kundenspezifischen Produktentwicklung unterscheidet (Eversheim, 2002), muss im gewählten Kontext von einer entkoppelten Produktentwicklung gesprochen werden.

## 16.5 Schlussfolgerung und Ausblick

Die globale Entwicklung von Artefakten durch operative Co-Creation Prozesse und die anschließende Herstellung in lokalen Produktionsnetzwerken wird weiter an Relevanz gewinnen. Beides bietet Vorteile in den jeweiligen Bereichen. In diesem Ansatz wurde das

Zusammenwirken der Netzwerke untersucht. So konnte ein besseres Verständnis vom Wertschöpfungssystem erlangt und Herausforderungen aufgezeigt werden. Dazu wurden die Netzwerk-Eigenschaften und Verhaltensweisen in den entsprechenden Bereichen hergeleitet. Die Untersuchung erfolgte dabei hinsichtlich drei Charakteristika: Netzwerk-Mitglieder, Netzwerk-Governance und Netzwerk-Maxime. So konnte der Netzwerkcharakter von Co-Creation Communities (CCC) und Cross-Company-Production (CCP) verglichen werden.

Beim Ergebnis dieser Analyse muss kritisch betrachtet werden, dass die drei gewählten Charakteristika unter Umständen nicht ausreichen. So könnte es sich bei der zukünftigen Prozessgestaltung herausstellen, dass weitere Kenntnisse über das Zusammenwirken notwendig sind, um eine Funktionsfähigkeit der Arbeitsprozesse zu gewährleisten. Zudem fehlt eine Auseinandersetzung mit den Auswirkungen auf den der Planungsvorbereitung (PV) hierarchisch untergeordneten Produktentwicklungsprozess.

Die gewonnen Erkenntnisse über das Zusammenwirken von CCP und CCC sind relevant, um zukünftige Prozesse der Zusammenarbeit effizienter gestalten zu können. Im Weiteren muss geklärt werden, wie den CCC hinreichend genaues Wissen über die Produktion bereitgestellt und gleichzeitig die Ziele (z. B. wettbewerbsrelevantes Wissen zu schützen) der CCP berücksichtigt werden können. Für weitere Untersuchungen stellt sich die Frage, ob eher die geöffnete, freiere Kommunikation bzw. die Öffnung des Kommunikationsprozess zwischen beiden Domänen oder der formalisierte Wissensaustausch zwischen den Domänen durch z. B. eine Standardisierung des Produzentenwissens für die Entwickler (Entwicklungsleitfaden, Konstruktionsvorgaben, etc.) zu einer besseren Erfüllung der Aufgaben und des übergeordneten Ziels zur Verbesserung der Produzierbarkeit beiträgt. In einem nächsten Schritt sollten die Gestaltung und Konzeption eines gemeinsamen Arbeitsprozesses angestrebt werden, durch den eine klare Abgrenzung und sinnvolle Aufgabenverteilung zwischen den verschiedenen Netzwerk-Akteuren ermöglicht wird. Dabei muss eine klare Zuweisung der Aufgaben eines Intermediärs (Broker) an der Schnittstelle zwischen Produktentwicklung und Produktion berücksichtigt werden. Die neuen, klar definierten Informationsflüsse in diesem zielgerichteten Wissensaustauschprozess müssen den negativen Folgen der Entkoppelung von Produktion und Entwicklung entgegenwirken. Im Weiteren sollten die Aufgaben hinsichtlich der Möglichkeiten zur Bewältigung mittels verschiedener Technologien untersucht und daraus eine Methodik zur Gestaltung eines anwendungsorientierten technologischen Systems hergeleitet werden.

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# Teil IV

# Local Production

# The Roles of Makerspaces for Facilitating Open-Source Hardware Development

17

Margit Hofer, Mehera Hassan and Robert Mies

## 17.1 Introduction

Fab City is an innovative urban model that re-localizes production to the city and its bioregional context. By empowering communities with the technology to build their own sustainable, innovative, and regenerative urban futures, the Fab City approach has been prominently linked to the OSH approach through (1) the Sense network developing environmental sensing technologies based on an all-in open (source) software/hardware/data model such as the Smart Citizen (Sensing) toolkit for citizens concerns (Diez, 2018, p. 200); (2) the REMODEL program, which created a design sprint for (Danish) manufacturing companies to identify new business models for engaging in OSH (Diez, 2018, p. 122); as well as, most recently within the Fab City Hamburg, (3) the Open Lab Starter Kit of OSH machine tools designed for makerspaces and the Interfacer project that develops a free and open-source tool chain for OSH (both subject of this book). These approaches consider a wide range of activities for a more sustainable and resilient technology- and citizen-based transformation of value creation within an OSH ecosystem. OSH can play an important role in enabling the transition to a circular economy, eliminating waste, and promoting the continuous use of resources by keeping them in closed loops through locally accessible distributed manufacturing supply chains, where products are

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designed to be reused, repaired, or recycled. Thus, makerspaces that facilitate OSH projects can act as central focal points for local production.

However, open-source hardware is still a relatively young field lacking a harmonization of practices and standards. Particularly, the scope of fab labs and makerspaces[1] as a frame of reference and intermediary actors within the FabCity approach have been overlooked regarding OSH development. This paper therefore explores the major role makerspaces can play as 'facilitators' for effective OSH development by small and medium-sized enterprises (SMEs) and start-ups based on collaboration and co-creation together with makers, customers, domain experts and many others as observed in the H2020 research project OPENNEXT as part of 17 SME cases. It investigates the challenges and opportunities for this still (arguably) new strategic orientation of makerspaces acting as facilitators for OSH, a critical cornerstone for enabling localized, digital, distributed manufacturing within the FabCity context based on a "data in data out" (DIDO) system of global knowledge sharing for maximized resource productivity in the future (Diez, 2018, p. 80).

## 17.2 Theoretical Background

### 17.2.1 OSH and Circular Economy

OSH development is a process of creating hardware products or devices using open-source principles, in a collaborative, transparent way within open-source-hardware communities or for the sharing of designs (i.e., broadcasting) and generative design. As it expands the idea of open source from software development, it focuses on hardware design, prototyping, and manufacturing which involves physical handling (Raasch et al., 2009). In OSH development, anyone interested can freely access the technical documentation of the hardware product (design files, schematics, etc.) on the internet. According to the definition of the Open Source Hardware Association (OSHWA),[2] open-source hardware is "hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design." This allows for a greater collaboration and more sharing of knowledge among developers, making it easier for them to improve the design, fix bugs, and add new features. The open nature of the process also means that the developed hardware can be customized and adapted to suit individual needs and preferences and enable decentralized production.

[1] Fab Labs stands for "Fabrication Laboratories" where so-called makers (e.g., designers, creatives, engineers, students and citizens) can "make (almost) anything" for local communities with digital fabrication tools from desktop machines to industry-grade equipment and creative spaces for peer-to-peer exchanges to invent and produce highly personalized products (Gershenfeld, 2012). The term makerspace comprises fab labs but also other types of hackerspaces and open workshops that all interested parties can access. For simplicity, we only refer to the latter in the remaining chapter.

[2] See https://www.oshwa.org/definition/

Thus, OSH can play an increasingly important role in the sustainable development and decentralized production. Makerspaces that facilitate OSH can thereby support the development and production of products that are repairable, upgradeable, and recyclable, which can help reduce waste and extend the life of products. Furthermore, OSH can also facilitate the development of new business models that support a circular economy, such as product-as-a-service or leasing models, where companies retain ownership of their products and customers pay for access rather than ownership. Overall, makerspaces have a high potential to support the transition to a more circular economy by enabling collaboration, innovation, and the development of more sustainable products and business models.

### 17.2.2 Collaboration in OSH

Collaboration is an essential element to many successful projects and initiatives. For OSH projects, it represented the driving force that pushed innovation and creativity and also resulted in long-term relationships and successful outcomes. Collaboration in OSH (and beyond) requires clear communication, mutual understanding, trust, and respect (Peters et al., 2022). The chances of successful collaborations are greatly increased if common goals, among e.g., SMEs, makers and makerspaces are set right from the start. When collaborating, it is important to remember that everyone involved has their own interests and abilities, resulting in different approaches. Thus, OSH collaborations need to make sure that all ideas are given a chance to be heard. At the same time, each participating maker and SME has certain expectations towards the result, the ways of working as well as the revenue. These are important aspects for the collaboration that need to be clearly communicated as well as organized and consolidated. Within the OPENNEXT project, new pathways for OSH collaborations were investigated by fostering a co-creation approach open to the public. Co-creation in OSH development is a process of developing a new product through teamwork with SMEs, makers, inventors, suppliers, customers, experts, and employees. The goal of co-creation is to promote the culture of sharing ideas, instead of keeping them to oneself, in order to improve productivity and sustainability (Ramaswamy & Ozcan, 2014; Kurzhals et al., 2022; Redlich et al., 2019). Consequently, these new, innovative forms of collaboration require networking and knowledge sharing, leading to a decentralization as well as a paradigm shift from traditional, firm-centric, and top-down value creation to more open and collaborative approaches, also referred to as bottom-up economics (Redlich et al., 2019). Makerspaces, by their nature, can fulfil exactly these new requirements. They are playing an increasingly important role in value chains of start-ups, specifically in funding, design, and production-related issues since they are cut out for experimentation (Tomczyk & Besenfelder, 2022). They create connections between SMEs and universities and match heterogeneous makers with communities, thus fostering new collaborations and providing a mutual benefit. Much diversity on the focus amongst makerspaces can be found, depending on the orientation of the makerspace/fab lab. They differ greatly in terms of equipment, orientation, motivation, funding as well as the communities and networks they attract. This diversity is a great strength and offers new opportunities for reshaping value creation. However, this raises the question how makerspaces can contribute to OSH product development activities and how they perceive their (own) role in this collaborative setting.

## 17.3 Methods, Concept and Research Approach

Based on this collaborative approach, within the OPENNEXT project, 17 different case studies were implemented in four clusters where makerspaces worked together with small and medium-sized enterprises (SMEs) for a limited period of time to provide new pathways for OSH co-creation and sharing. A wide range of topics and aims was covered in these OSH projects, including designing furniture, developing environmental sensors or tools and add-ons to transportation. While two makerspaces were predominantly commercially driven (MAKER in Copenhagen and HappyLab in Vienna), two other ones (WAAG in Amsterdam and Prototypes4Europe in Berlin) were more community-driven. Based on this overall research setting, OPENNEXT investigated how makerspaces can contribute to OSH product development activities and how they perceive their (own) role in this collaborative setting. The aim of the analysis was to understand how makerspaces can contribute to OSH product development activities and how they perceive and assume their (own) role in this collaborative setting.

As only limited discussions regarding these two questions were found in existing literature, to get more insight, other than providing a platform for OSH co-creation and sharing, the OPENNEXT project included observational research tasks. This was done through four semi-structured interviews with the makerspaces, three makerspace discussion forums and one reflection workshop involving all four makerspaces. The analysis of the qualitative data from these activities provided an understanding of the complexity of particular roles involved in the process and, at the same time, highlighted the broad range of tasks involved. To achieve synergy and derive priorities in the results, the makerspaces were encouraged to discuss, comment, and share their views during the reflection workshop. The interviews and the discussion forums as well as the reflection workshop were transcribed. The material was analyzed qualitatively (Mayring, 2014), extracting the roles of makerspaces by a hybrid process of deductive (derived from the research questions) and inductive coding approach, allowing for new, unexpected categories and codes (Flick, 2014). Derived from theoretical background and the research questions, initial categories of 'collaboration', 'tasks', 'makerspace roles in C3' and 'project phases' were identified. New categories and subcategories (inductive codes) were identified during the coding with the tool MAXQDA. In total, 733 codes were identified, while explicitly 434 codes were extracted in relation to makerspaces' different roles and tasks in company-community collaboration.

Consequently, this allowed for a first categorization of tasks that enabled the identification of core roles of makerspaces in collaborative OSH project settings.

## 17.4 Results

While the term 'makerspace' is used generally for all creative environments which are based on the maker principles, these spaces can take different forms in terms of organization, where they are established, available tools, and what is being focused on (Schön et al., 2014).

### 17.4.1 Types of Makerspaces

When it comes to OSH development, the type, focus and direction of the partnering makerspaces played a major part in their cooperation with the SMEs and corresponding communities in terms of the values they brought to the table as well as the ongoing dynamics throughout the different phases of collaboration as part of the OSH development projects. Accordingly, two main types of makerspaces could be distinguished, i.e.:

- Technology-focused and business-driven
- Collaboration-focused and community-driven

**Technology-Focused, Business-Driven Makerspaces** Enabled by ICT infrastructure and digital fabrication tools, such as 3D printing, and facilitated by shared workspaces, such labs provide the needed machinery and equipment as well as the technical know-how to facilitate OSH development activities ranging from design, prototyping, and actual production of small-patch production within its premises for many businesses in a creative environment. Functioning as stand-alone or affiliated organizations, such labs adopt various business models driven by economic sustainability and social impact.

Present as local open workshops, the technology-focused makerspaces offer the needed infrastructure to facilitate local manufacturing opportunities both for individuals, groups, and even business enterprises such as small and medium-sized enterprises to develop and scale products pushing the boundaries of urban and local productions in a globalized world. Being business-driven, means for this type of makerspace that they focus on continuous diversification of their offering to their current members, attracting new members, and exploring strategic collaboration with local businesses and startups creating a win-win economic value to all parties. Examples of such makerspaces include HappyLab in Vienna (https://happylab.at/) and Foreningen Maker in Copenhagen (https://maker-effekt.dk/).

**Collaboration-Focused, Community-Driven Makerspaces** This type of makerspaces focuses on the human factor and centers its activities around the question "who makes it?" Organizations belonging to it provide creative environments set up by local communities, schools, museums, and other public or civic organizations with a focus on creative forms of engagement, not only with makers but also with general and non-technical citizens to bring in their own interests and concerns. Such makerspaces bring along a wide network of citizens and groups of makers engaging in topics affecting the common good. The products and services created by and within such makerspaces are wide-ranging and include, for instance, domains such as: environmental sensing, the questioning of potentially harmful applications of biotechnologies, concerns of privacy and security in digital public spaces, and many more.

This type of makerspaces engages closely with citizens, civic society organizations, cities/municipalities towards creating agency, and the inclusion of the general public and other local stakeholders in shaping the development of a sustainable society maneuvering the ever-changing technological and social challenges. With a citizen-centric mindset that also considers the disadvantaged and most vulnerable, these makerspaces bring local technology businesses and manufacturers together with communities of interests and concerns to find new innovative ways to address their needs, technology acceptance, and socio-ecological impacts. This brings valuable insights to the product development team and an opportunity to participate, shape and influence the development of products for a more sustainable future. Examples of such labs are the Waag society in Amsterdam (https://waag.org/) and Protoypes4Europe e. V. in Berlin (https://www.prototypes.berlin/).

### 17.4.2 Roles of Makerspaces

These two main types identified tasks in respect to the OSH cases of the SMEs they were matched with and assumed different corresponding roles. When done comprehensively, six roles were observed as relevant for makerspaces facilitating an OSH development project: acting as a matchmaker and broker; being facilitator for prototyping and exchange; organizer and moderator of communication; promoter of collaborative working culture; manager of the co-creation processes; and enabler of the understanding of roles, motivation, and responsibilities (see Fig. 17.1 below). These roles can be taken up flexibly, depending on the specific OSH project scope, the participating makers, SMEs, and the makerspaces: while some OSH projects need more support in finding additional makers with different skills, others might need more support in aligning the different interests of the final OSH product. Usually, OSH development is a process over a certain time period. Makerspaces should be aware that during this process, needs will change. Thus, the required roles and the degree of their engagement will vary throughout the different development stages. The roles are diverse, however, they do not necessarily need to be exclusively filled by makerspaces, hence, they can also be taken over by other actors.

**Matchmaker, Establisher of Communities** Makerspaces are diverse places that foster creativity and innovation, and they often already have OSH communities established. Nevertheless, it is the daily business of makerspaces to grow their communities and col-


**Fig. 17.1** Overview of roles of makerspaces in collaborative OSH development

laborations. Most importantly, makerspaces know their makers and their communities. Consequently, they can act as a perfect interface between industry, (maker) communities and consumers as well as universities: “[A] makerspace should be the communicator between the company who is joining in and the makerspace community. They know all their members and know their interests and profiles … thus can form the right team” (Happy Lab Vienna). To maximize the potential of the collaborations with companies, it is beneficial for makerspaces to match SMEs with makers they already know. Pivotal to the brokering are not only the needed skills of makers but also common interests, motivations and aims as part of the defined project scope. Makerspaces can channel the dynamics of collaboration: “Company-community collaboration doesn’t happen without the makerspace as a broker” (Prototypes4Europe, Berlin). Thus, the collaboration is rather a triangulation between community, makerspace and the company: “It should be ‘community-makerspace-company’-collaboration” (WAAG Amsterdam).

The OPENNEXT makerspace partners saw their own role exclusively as brokers, facilitators and enablers of the OSH process itself, but they prefer to avoid any direct involvement in the industry: “I don’t think that the organization should involve too much in doing bigger commercial projects, because it’s not where we’ve been put in this world to do. I mean, we’re not a consultancy, we’re an association with members who are physical entrepreneurs. So, it’s not our job to do these big commercial projects” (Maker, Copenhagen). The makerspaces see themself rather as a brokerage support that facilitates the development process, yet they reject to liken their role to consultants or broad manufacturers in a traditional sense.

**Provider of Infrastructure and Training and Prototype Facilitator** Makerspaces, according to their origin, understood their primary role mainly as providers of infrastructure (Gantert et al., 2022). They enable makers and inventors to use this infrastructure (tools and machines) at their premises based on different financing models. Offering a space and respective tools to commonly design, promote and market a product idea through and within the makerspace can generate beneficial outcomes: a collaborative approach of OSH development can benefit greatly from face-to-face meetings of the team, as it creates a common ground allowing for exchange and discussion (Dai et al., 2020). Physical products should be discussed physically for a better understanding and outcome. Often, neither SMEs nor makers can provide sufficient spaces that allow for creativity and innovation for all involved team members. Consequently, not only do makerspaces operate for manufacturing purposes, but they also provide an added value through the availability of space for workshops, hackathons, or simple team collaboration. Many makerspaces also offer a variety of training courses to educate their members, the community as well as the general public on the safe and proper use of the available equipment and tools for design and manufacturing. Collaborative OSH projects might require specific training that goes beyond these general-training topics. A major skill for makerspaces is to identify the timing when support (training) is needed to foster and bridge the collaboration between makers and SMEs. This may differ from project to project but also depends on already existing knowledge, skills and experiences of SMEs and makers.

**Communicator and Moderator of the Development Process** Organizing and running workshops and events is a core task for most makerspaces. A makerspace in an OSH development may organize an innovation workshop in which all team members become familiar with the spirit of a collaborative OSH project, the individual perspectives of the other actors and facilitate a mutual understanding and agreement of the objectives, which is essential to successful collaborations. These events are vital since they establish the same understanding of aims and expectations and bring forward the necessary actions and steps. These events also serve to align the different communication patterns from SMEs and makers. Makerspaces can help by taking over the role of "interpreters, translating between the makers' language and the business's language" (Happy Lab Vienna). By offering an alternative to primarily company-branded events, makerspaces can attract different stakeholders gaining manifold perspectives to a workshop, gather inputs from independent experts on specific topics, and moderate the articulation of different goals and expectations of the participants. The OPENNEXT makerspace partners consistently agreed that the management of the communication with the makers as well as the SMEs is highly sensitive and should be taken seriously to balance interests and motivations. Adequate communication and moderation of OSH development is also a time-consuming task; a fact that is easily underestimated.

**Facilitator of Working Culture** Makerspaces are rarely just places of fabrication. Rather, they are hubs of communities, where people work together, learn from each other, or simply socialize. At the core, makerspaces are places for making, but the aspects of collaborating, learning by testing and exploring as well as sharing are as important as the making itself. The culture of makerspaces is based on the foundations of an open-minded approach, trust, flat hierarchies, generation of constructive and honest exchange and rapid feedback. Makerspaces can also implement a quite specific working culture in OSH projects that allows for a flourishing of co-creation and collaboration. Thus, typically, the role of the makerspace is to ensure that the collaborative work is done on equal footing. The maker culture compared to the business culture can differ greatly in as much as that it can be much more value-driven: "The open-source approach defines our values and the way we do things" (WAAG, Amsterdam). Consequently, an important issue for makerspaces in respect to OSH product development is to emphasize the attitude of trust as well as an open-minded approach. This value-driven approach of co-creation that was followed up by OPENNEXT makerspace partners was considered to be extremely valuable in the OSH cases, due to its ability to bring about unexpected new outcomes with the help of innovative perspectives of a heterogeneous group of innovators, tinkerers and makers combined with SMEs.

**Advisor on Identifying Roles, Clarifying Expectations, Responsibilities and Visions** An OSH project may bring together makers, SMEs, universities, or individuals, working to develop and complete an OSH project successfully whilst all following different motivations. When organized well, OSH project contributors work closely and have clearly defined roles. Consequently, developing a shared vision of an OSH project among the diverse communities and the implication for the developed product is pre-conditional and can be an important task of a makerspace. They can facilitate a clear division of responsibilities and align realistic expectations on goals and tasks.

**Coordinator of Co-creation Processes and Coordination** Overall, there is no "one size fits all" model of a makerspace and SME collaboration. Makerspaces often assist their members with project management, documentation, and other operational tasks. Prototyping is a fun and interesting activity that is part and parcel of the development. In fact, it is one of the most important aspects and proper project management is vital in order to succeed with prototyping: "It has been crucial to the process and success of the project that Maker Denmark has connected the dots, driven the process forward and arranged deliverables and security for all participants, being TRP [transparency, responsiveness, and partnering] or community" (MAKER, Copenhagen). Successful OSH projects always document properly, point to deadlines or understand the needed effort, for example. Makerspaces can provide a managing frame by stressing the importance of a constant and well-implemented design process organization or the creation of links to domain experts. Due to their experience in product development, makerspaces are also highly competent in selecting appropriate tools: "Too many new tools and workshops can interfere with your focus and development stage. Which is a very intense stage in the process of creating products" (Maker, Copenhagen). On a very practical level, makerspaces handle false expectations. Especially the time investment of both, makers and SMEs, is often underestimated. The clarification of this effort is crucial for a successful OSH project.

## 17.5 Discussion

In this paper, we have identified tasks that are highly relevant for makerspaces when facilitating OSH projects. By structuring these tasks, we created a framework of roles for makerspaces. Makerspaces, due to their origin, are a predestined fit for facilitating collaboration and co-creation and can realize great synergies for the benefit of social economy, particularly SMEs and start-ups but also makers and individuals as well as communities and society as a whole. Not all the roles observed from the OPENNEXT makerspace partners were present in all makerspaces at the same time and to the same extent. It heavily depended on the scope of the OSH project, the experience of the makers and SMEs as well as the different identified needs. Consequently, each OSH project required a different emphasis on the roles. As an example, business-orientated makerspaces might be required to provide machines and tools rather than actions as moderators (see Fig. 17.2). Several roles are requested at the beginning of a project (i.e., matchmaking – inner grey circle initial phase), while others may then start at a later stage (i.e., provider of facilities, coordination, amongst others). Moreover, the need to take up certain roles also depends on the individual stages or phases of OSH projects.

Makerspaces that have a clear understanding of their roles and responsibilities in OSH projects are in a better position to effectively foster collaboration and successful completion of projects. In addition, makerspaces need to understand what skills and abilities are expected from them to be able to fulfil these roles, involve their local maker community and integrate these new roles and sets of activities with everyday "making" activities.

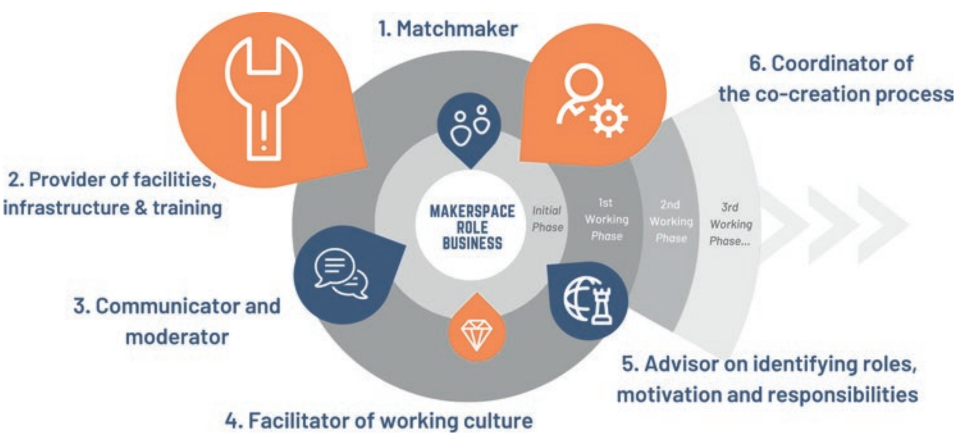


**Fig. 17.2** Exemplary roles of makerspaces

### 17.5.1 Benefits and Impacts of Collaborative OSH Development

The potential of well-working OSH projects and their potential future benefit is highly relevant to distributed manufacturing and open sharing. From an ecological perspective, OSH is significant since it bypasses long transport routes and supports solutions to close local material cycles. OSH avoids restrictions and dependencies of, in comparison, centralized approaches, through its basis on a federated approach. This collaborative approach in OSH adds to a social inclusion and sustainability since knowledge and know-how is openly shared and adapted resulting in unrestricted and adaptable production.

As outlined, OSH is ideally already a part of makerspace values like sharing, co-creation, and knowledge distribution. Yet besides this already existing alignment, what other benefits and impacts did makerspaces experience during their facilitation of the OSH cases within OPENNEXT? For one, makerspaces claimed that they gained new knowledge, new networks and strengthened existing ones. They saw additional business opportunities due to the experience gained in the development and implementation of OSH projects as well as the perceived satisfaction of becoming experts in OSH facilitation. They were able to contribute to systemic change through promoting OSH and demonstrating well-working examples.

Asking makerspaces what benefits and impact for SMEs were observed, they claimed that SMEs benefited most from the direct engagement with makers, innovators, and experts. The access to (local) facilities for testing, development and experimenting resulted in empowerment and engagement and, further, to a change towards a new innovative systemic and inclusive approach. Another advantage was the gaining of new knowledge through the training received from makerspaces. OSH activities overall contributed to a new mindset and perspectives of the SMEs and a different way of scaling. On a practical level, SMEs recruited makers in some cases permanently, thus benefiting by finding skilled employees.

### 17.5.2 Considerations and Recommendations for Makerspaces Facilitating OSH

The increasing interest in OSH for regional development in different economic areas bears both chances and risks for makerspaces. Their competencies have a high potential to act as a central focal point for distributed manufacturing, considering several aspects which are elaborated and derived as recommendations in the following.

**OSH Makerspaces Foster Innovation by Acting as Incubators** According to the interviews with the makerspaces, collaboration between makers and SMEs does not happen by itself but rather needs support from a third party. Makerspaces are in a well-founded position to provide new opportunities for OSH development, as it is in the makerspaces' DNA (see WAAG, Amsterdam). By providing communities in combination with the (technical) facilities, makerspaces can be a powerful intermediary between diverse makers and SMEs for OSH. However, the openness of a shared space and knowledge as well as the co-creative approach is mostly new to SMEs. At the same time, it might be a challenge for a community of makers to work with SMEs. Makerspaces need to bridge this transition towards a more innovative approach to business, provided they conform with the identified roles.

**OSH Makerspaces Need to Align (or Professionalize) with New Tasks and Roles** As shown, these revealed roles are highly interdisciplinary but inevitable for makerspaces to act as successful incubators of innovation. Many makerspaces already comply with some of the described tasks and roles but with a limited scope. Facilitating OSH projects however requires increased and flexible efforts in collaboration, communication, and management tasks. Other tasks, like bridging innovative makers and SMEs or fostering the understanding of the makerspace culture to new target groups, were new to them. Consequently, makerspaces will need to scale up their portfolio and will have to increasingly professionalize already existing roles.

**Evolving from Classical Makerspace to Innovative OSH Makerspace** Further, makerspaces originally defined themselves as "… places where people came together to create and invent things using crafts or technologies, allowing individuals with different abilities and interest to fulfil their talent. They were associated with like-minded people coming together driven by personal interest for purposes such as common good and fun" (Vuorikari et al., 2019). As the analysis of the interviews has shown, the matchmaking between communities and SMEs is one of the major assets of makerspaces. Thus, it is essential for makerspaces to maintain a very close connection to their community. Shifting the focus towards OSH projects will need to go along without fear of becoming 'institutionalized' for industrial prototyping or becoming part of established structures in the wider economy.

**Expanding Collaborations and Costs** While this report focused mostly on the collaborations between makerspaces and SMEs, the field of other regional stakeholders is rich in cultural/social organizations, educational entities, non-governmental organizations (NGOs), and private sector actors who work with diverse groups. Next to a significant amount of time that has to be invested, an expanded OSH collaboration to other stakeholders is associated with an increase in flexibility and costs, i.e., for hosting workshops or inviting experts. This should be offset by the created multidimensional benefits for the maximization of the social economy, which requires future research for appropriate assessment schemes as well as quantitative and qualitative metrics.

**OSH Implementation on Large Scale** Investments from the wider economy in OSH is still at a low level. Unsolved potential liability (Staed, 2017) risks with OSH products as well as highly bureaucratic, untransparent product certification processes and a lack of standardization (Bonvoisin et al., 2020) hinder the implementation on a broader scale. OSH can have a significant impact on the economy, society, and environment, but its reach and scalability are often limited. Most OSH is only used by a few applicants, consumers, or groups. OSH is still a niche and considered to be an inferior alternative to commercial products. Incentivizing good practices in integrating makerspaces and making activities could help overcome this shortcoming. Also, the understanding of the new, innovative product development that is done by a collaborative approach requires a re-thinking by the industry. Therefore, new attractive business models need to be created underpinning the economic benefits.

## 17.6 Conclusion and Outlook

Using structural qualitative analysis, the authors analyzed six different roles of: match-maker, provider of facilities, communicator, facilitator of open working culture, advisor on clarifying roles, and coordinator of the co-creation process. Being in the position to foster innovative OSH development, makerspaces can fill the gap as catalysts to provide critical skills and infrastructure as well as support shared knowledge and amplify effective OSH development with the effect of maximizing the impact on economy and society. They need to position themselves in the role of promoters for distributed manufacturing, boosting local value creation. Through the facilitation of makerspaces acting as an intermediary between economy and society, OSH projects could indeed get initiated by or adapted to local and individual needs of makers by SMEs and start-ups, leading to a decentralized production whilst opening up for global collaboration and knowledge sharing.

The identified six roles were case-based and emerged to be essential in facilitating OSH projects of SMEs with makers, customers, and citizens. Nevertheless, this change towards a more OSH development orientation might have a considerable effect on the makerspace's overall orientation and internal organization. High flexibility and adaptation to the different needs of the engaged OSH team members is required. While some OSH projects might need more support in communication, other projects could challenge the makerspaces with increased match-making requests.

However, other intermediary actors and public infrastructure will be needed in future. As described, the foundational knowledge and infrastructure already exists in open-source hardware communities. If policy initiatives further support OSH-related efforts of makerspaces, it could help them grow their communities, further expanding the capacity for innovation, collaboration, and decentralized production (primarily for SMEs and start-ups).

Finally, a collaborative OSH development can play a significant role in supporting local manufacturing, especially when addressing local needs and issues. Sharing the outcome and the gained knowledge allows the wide spreading of these solutions and, thus, can serve well as an incubator for a more distributed production in the future.

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# 18 On the Usability of Open-Source Machine Tools

Luisa Lange, Sonja Buxbaum-Conradi, Manuel Moritz, Jacqueline Bertlich, Tobias Redlich and Jens P. Wulfsberg

## 18.1 Introduction

The enthusiasm about open-source and open-source hardware has rapidly increased during the last decades (Pearce, 2017; Spaeth & Hausberg, 2016). More and more products are being designed and produced in an open-source manner. Starting from open-source cargo bikes (Wolfer, 2023) through solar control boxes and panels (*The Libre Solar Project*, 2023) to OSMTs (*Open Lab Starter Kit GitLab*, 2022) (OSHWA, 2022).

However, many of the open-source developments have one aspect in common: they have been developed by engineers for engineers with a focus on functionality and proof of concept (Andersen, 2012). Especially open-source machine tools (OSMT) show a high level of technical complexity (Omer et al., 2022). This can be difficult for users of the machines that have not been included in the development and build process or in general for users with no particular technical background. Thus, if we want the concepts of Fab Cities, prosumers, and local production to actually reach citizens and encourage participation in production, we also need to ensure accessibility and usability of the open-source hardware involved in these projects. A better understanding of factors influencing the usability of OSMTs is fundamental to reaching this goal.

A core part of the open-source movement are makerspaces and their state-of-the-art open-source machine tools (Omer et al., 2022). Since research on OSMTs is still nascent, no research has been done in regards to their usability. Therefore, an explorative qualita-

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tive study was conducted, focusing on the usability of OSMTs in the maker movement in the Fab City Hamburg.

## 18.2 Theoretical Background

### 18.2.1 Open-Source Machine Tools (OSMTs) in the Context of Open-Source Hardware

Open-source hardware is a section of open-source and follows the general principles of open production (Redlich & Wulfsberg, 2011). Open-source hardware is defined by the Open Source Hardware Association as follows: "Open-source hardware is hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design" (OSHWA, 2022). Similar to open-source software, open-source hardware benefits from increasing online collaboration. Designs of open-source hardware are being developed all over the world, shared digitally and replicated locally (Boujut et al., 2019).

The concept of open-source machine tools (OSMTs) as such was first introduced by Omer et al. (2022). Omer categorizes OSMTs as machine tools that have been developed and made accessible in an open-source manner. OSMTs form an important part in the further development of open labs, for example, as foundations of the Open Lab Starter Kit (*Open Lab Starter Kit GitLab*, 2022). Since the concept of OSMTs as such is still rather new, no subsequent studies in this field have been published. Therefore, no studies have been conducted on the usability of OSMT.

### 18.2.2 Usability of Machine Tools

The term usability is defined as the "extend, to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (Deutsches Institut für Normung, 2018). However, the DIN norm keeps the definitions and concepts rather general, with no specific focus on the usability of machine tools (Deutsches Institut für Normung, 2018).

In general, usability of machine tools outside the open-source context is also a field that has not gotten much research attention. Studies on usability of machine tools mainly focus on the improvement of technical functionality (Brecher et al., 2011), or on the improvement of effectiveness and efficiency of processes as stated in the DIN EN ISO 9241-11 by Deutsches Institut für Normung (2018) Recently, problems of usability of machine tools have arisen due to an increasing complexity caused by higher degrees of automatization and digitalization in industry described by Puschmann et al. (2019). The authors focus on occurring errors during the use of machine tools and recommend rule-based error prevention to deal with this issue (Puschmann et al., 2019).

One related aspect which is often considered when talking about human errors and usability is the cognition of users. Cognition is defined by Wogalter et al. (2012, p. 871) as a "core area of psychology that is concerned with mental processes such as attention, memory and decision making". Usability assessment and testing often focus on this cognitive area of the users. Practices such as a cognitive task analysis (CTA) or a cognitive walkthrough are common methods to determine the usability related to human actions, for example, for websites or interface testing. Those practices focus on the way a user describes and interacts with different tasks (Sharit, 2012; Vu et al., 2012).

Another area of usability studies focuses on users and their emotions related to the use of a machine: affective engineering and design. The field, however, mainly covers consumer products (Helander & Khalid, 2012). One area of affective engineering is Kansei engineering, which uses semantic methods to analyze the user's emotions towards a specific design or product (Helander & Khalid, 2012). Liu et al. (2013) describe a first approach studying the design of machine tools based on Kansei engineering.

Combining these areas, Camerer et al. (2005) introduced a two-dimensional characterization of neural functioning which divides the neural activities of a person into cognitive and affective processes which either happen in a controlled or an automatic way. Helander and Khalid (2012, p. 572) highlight the importance that "cognition must consider affect or emotion and vice versa".

Previous work describes a field study in the industrial sector of machine tools, concluding with the concept that not only affective and cognitive systems must be considered together, but that also the technical system as such is an essential part of overall usability. During this study, several different partners from industry, including machine tool developers and machine tool educators have been interviewed with regards to their perspective on usability issues of digital machine tools. In addition to the interviews, user observations had been carried out. In this study, the interaction between the technical, the cognitive and the affective dimensionhave been explained and determined. For further details see Lange et al. (2023).

The technical dimension comprises all influences with regards to software and hardware functions of digital machine tools. Among others, it includes the influence on the factors of machine tool complexity, the number of parameters and their proper settings, interface design, frugality of the machine tool, and the level of automatization and digitalization. The cognitive dimension includes all processes that a user goes through whilst using a digital machine tool. This includes the factors of a general process understanding, pre-knowledge about the machine's functionality, the learning and teaching process, as well as previous experiences whilst using digital machine tools. The affective dimension covers all aspects related to emotions. This includes negative emotions such as fear of operating the machine incorrectly, as well as positive emotions such as motivation, trust, pride or a feeling of safety, whilst using the machine tools. Furthermore, the importance of considering the interconnectivity between these dimensions is highlighted. Factors associated with machine tool usability are not only affected by one of the dimensions but are rather interconnected between the three dimensions and influenced by all of them (Lange et al., 2023).

It is important to note that these dimensions have been consolidated in an industrial context. The authors used this basis to create a connection to the open-source context. Therefore, the following research question arises: which socio-technical factors influence the usability of open-source machine tools, and how can they be categorized along the three dimensions to generate a holistic approach on OSMT usability?

## 18.3 Method

An explorative, qualitative research approach was chosen, to determine the status quo of OSMT usability and its consideration during the development process as well as the common problems that users and educators see, when it comes to the usability of OSMTs.

At first, a question guide for semi-structured interviews was developed and tested. Interviews were then conducted with six OSMT developers as well as six OSMT educators. It was important to the authors to cover both the development as well as the educational aspect to gain a holistic view on the current approach on usability within the community. Based on the Grounded theory approach by Glaser and Strauss, the questions of the interviews were already iterated and adapted in between the different interviews. Through this constant reflection on the data, a deeper focus on the actual problems of usability could be reached. The interviews have been recorded and subsequently transcribed for further analysis.

Following the interviews, over 17 hours of user observations have been carried out in Fab Lab contexts. The observations were mainly made during workshops and regular lab operations, where the interaction of users and the machines were studied and compared to the information previously gathered in the interviews. A focus was hereby set on common problems and issues that users faced when operating machine tools, as well as their coping mechanisms with these issues.

Additionally, the authors also visited the Maker Fair in Prague to get an international perspective and to reach more developers outside the Hamburg community. The authors informally talked to different developers at the fair and listened to their approaches on usability. Here, a focus was set on topics that had already come up during the initial interviews. Especially the strategies considering usability during the hardware development process have been inquired. Subsequently, manuals, documentations, and repositories of OSMTs have been analyzed. An overview on the data gathered can be found in Table 18.1.

**Table 18.1** Overview on gathered data

| Interviews | Observations | Practical interactions | Document analysis |
|---|---|---|---|
| 6 OSHW workshop instructors | ~ 10 hours Open Lab days | >10 OSHW developers Maker Fair Prague | Open-source 3-D printer repository |
| 6 OSHW developers | ~ 7 hours workshops | | Open-source laser cutter repository |

All this data was gathered and subsequently coded and analyzed. Based on this analysis, different factors concerning the usability of OSMTs were identified, interlinked and interdependencies among the factors were detected.

## 18.4 Results

The data analysis focused on investigating the three dimensions of usability which had already been detected in the study on machine tool usability in industry by Lange et al., 2023. The technical, the cognitive and the affective dimension have also appeared in this study. Even though the main concepts are similar to the ones detected in the industry, the cause and correlations differ in the open-source environment. Especially the focus of the open-source community and the active involvement of users, also during the building processes and early stages of prototype development, led to a wider understanding of usability and participant involvement.

Within the three dimensions of usability, many influencing factors on usability of OSMTs were detected. An overview of the top 20 factors and their connected core dimensions can be found in Table 18.2. It is important to keep in mind that this table is merely a reflection of the interviews and by no means mutually exclusive and collectively exhaustive.

**Table 18.2** Identified main factors influencing the usability of OSMT

| Core dimensions | Factors |
|---|---|
| Affective dimension | **Atmosphere/prevailing mood while using the machine tool**<br>Fear of breaking the machine tool<br>Fear when using the machine tool<br>Motivation of the user<br>Way of dealing with mistakes/fault tolerance |
| Cognitive dimension | Amount of taught content<br>Intuition of the interface<br>Language of the interface<br>Pre-knowledge on the processes<br>Previous experiences<br>**Process understanding**<br>Social background of the user |
| Technical dimension | **Complexity of the machine tool**<br>Interface of the machine tool<br>Machine tool standards<br>Reliability of the machine tool<br>Resources during the development process<br>Workpiece design |
| Technical and affective dimension | Machine tool feedback |
| Technical and cognitive dimension | Parameters and settings |

The most prominent factor of each dimension (marked in bold in Table 18.2) was chosen for further examination: process understanding, machine complexity and the atmosphere/prevailing mood during machine use. These factors are now presented in more detail.

### 18.4.1 Process Understanding

The factor of process understanding is probably the most significant aspect in regard to usability. According to the interviews, the fact that users have the need to understand what is happening when using the machine remains undoubtedly one of the core influences on the later usability of a machine tool. Here, one aspect in the open-source context has a great impact on the process understanding: the ability of actual participating in the replication and building process of an OSMT. When users actively participated in the building of machine tools, different educators have noticed a deeper process understanding on their side:

> Simply the understanding of the interconnection within the machine increases. Because they have now assembled it themselves. So, for example an end stop sensor was attached somewhere and this end stop sensor was connected via a cable and then connected to the 3D printer control board. (OSMT educator)

Even if users are not actively involved in a building process, the understanding of it can be increased by the openness of the documentation and, for example, an easier insight into maintenance and repair works.

Process understanding is primarily associated with the cognitive dimension of usability. However, it is also connected to the other two dimensions. The technical dimension influences the factor of process understanding. A simpler and less complex product design also facilitates the process understanding as such. The affective dimension, in return, is influenced by the factor of process understanding. A higher process understanding leads to the user's ease within the affective context. An alteration in each of the dimensions directly influences the overall usability of the OSMT. This interconnection is visualized in Fig. 18.1.

### 18.4.2 Machine Tool Complexity

Machine tool complexity is a factor that has come up in the industrial as well as the OSMT context. This factor is largely connected to software and hardware design of machine tools. However, the focus during the development process in the open-source environment is currently mainly set on a machine's functionality. Also, developers stated that they have to use whichever software or hardware solution is available open source. This leads to an increasing complexity of the final OSMT. One developer describes the problem as follows:

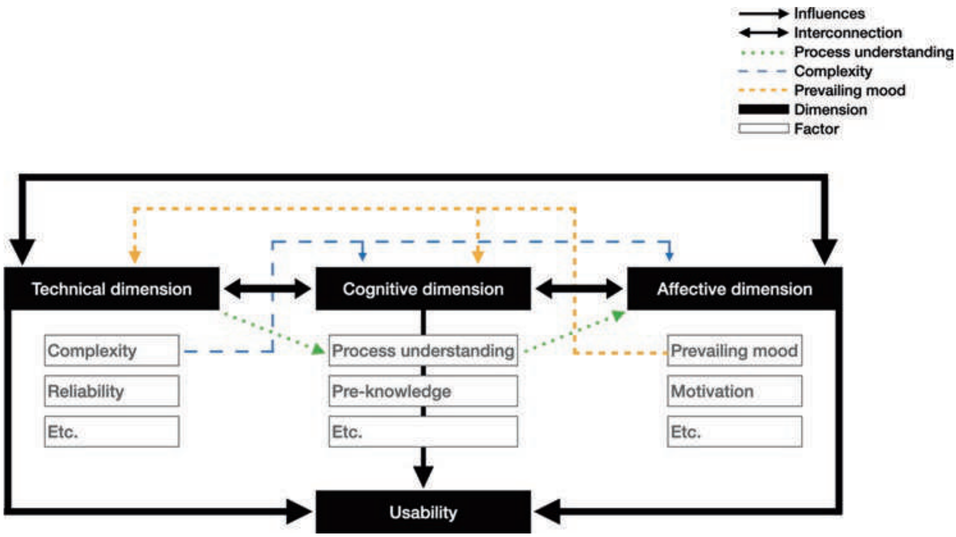


**Fig. 18.1** Influences on the different factors

> We need three softwares. And it would be much better if it was just one. But what can we do? [...] If you don't have someone to code and do something specifically for your needs, you have to deal with these Frankensteins. (OSMT developer)

However, some of the OSMT developers are already aware of this situation and try to come up with possible solutions to minimize the complexity for the final OSMT user:

> Just minimize all of the possibilities of them doing the wrong things by minimizing the components they can interact with. Building things in the background, so the consumer doesn't even know they are there and making them look nice and intuitive. (OSMT developer and usability expert)

The factor of machine complexity is mainly located in the technical dimension. However, it largely influences the cognitive and affective dimension. A higher complexity leads to a larger effort in process understanding and at the same time lowers the ease within the affective dimension. The interaction between the factor and the dimensions is also shown in Fig. 18.1.

### 18.4.3 Prevailing Mood

Another aspect that was mentioned several times in the interviews was the focus on the community and the importance of the prevailing mood that an open lab environment creates for users. By creating an atmosphere where trial and error is part of the game, users are encouraged to perceive OSMTs differently. Many users and developers mention the fear of “breaking the machine” that often occurs during first interactions of users and machine tools. However, the open-source context focuses more on engaging users in the process of creating, maintaining, and optimizing the machine tools, helping the atmosphere of learning and curiosity.

With regards to the three dimensions, the prevailing mood falls within the affective dimension whilst also influencing the other two dimensions (technical and cognitive) as shown in Fig. 18.1. The open-source community has a strong impact on the development process of OSMTs. Developers, for example, try to consider the social backgrounds of users or the way users react to machine issues. This aspect indirectly influences the development process of OSMTs and therefore also the technical dimension. The learning environment which is created in open labs – highly connected to the cognitive dimension – is also influenced by the general atmosphere within an OSMT context.

The three identified main factors shown in this chapter have been described by way of examples. However, each of the other factors listed in Fig. 18.1 can and should also be considered in the context of OSMT usability. In general, this concept shows how the three dimensions (technical, cognitive and affective) can be considered when specific factors that influence the usability of OSMT are dealt with. Developers, educators and lab managers should keep this holistic view on the interconnection between the dimensions in mind when working with or on OSMTs.

## 18.5 Discussion and Outlook

Since the field of OSMT usability is a very new concept, an explorative study has been carried out, building on former works on usability of machine tools in an industrial context.

The three dimensions of usability: technical, cognitive, and affective dimension, described in previous works, have been further pursued and connected to major factors that influence the usability of OSMTs. 20 main factors that influence the usability of OSMTs have been identified and three factors have been outlined by way of an example to showcase the interconnection of the three dimensions and each factor: *process understanding, complexity of the machine tool* and *the prevailing mood/atmosphere*. By doing so, the authors have illustrated the interconnection between the three dimensions of usability, with regards to specific factors influencing usability. These factors may vary for each machine tool, however, the outlined holistic approach is transferable to all factors.

Even though the researchers set a focus on interviewing experts from different social and cultural backgrounds, the observations of the users had mainly taken place in the Hamburg area. Therefore, further studies in different contexts are suggested. Additionally, the chosen research approach was inductive. The next steps would be a theory-testing study in the field to see whether the three dimensions of usability can be applied to different contexts.

It can clearly be noted that the open-source environment has an impact on the development and design of OSMTs. Depending on the function and respectively important factors of OSMTs, different aspects can be considered during the development process, to enhance the machine's overall usability. However, the approach on usability described in this chapter bears a great potential for future developments of both, proprietary machines as well as OSMTs. Especially the cognitive and affective dimensions can be transferred to other "non-open-source" machines used in open lab contexts. The authors think that this approach can be of great advantage in the open-source and Fab City community since the affective and cognitive dimension can be highly influenced by open lab contexts. By focusing on these three dimensions of usability, more users can be encouraged to participate in the local production and repair processes of a Fab City.

Therefore, developers, educators and users of machine tools should be aware of this great opportunity and keep it in mind during the development of their products, education plans, or simply whilst using the machine tools available in the labs. Open-source is so much more than just the products – it is a mindset and a community. And this is also true for the development and usage of OSMTs.

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# Enabling Technology Diffusion with the Open Lab Starter Kit

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## 19.1 Introduction

Fabrication laboratories, often referred to as Fab Labs, are public spaces that aim to make the means of production available to anyone. They provide uncomplicated access to digital fabrication tools. While Fab Labs have been hailed as disruptors of the established manufacturing practices that rely on economies of scale and largely exclude individual makers, they have hitherto failed to provide a truly equal access to digital fabrication machines. Their potential for grassroots technological emancipation is largely limited to the global north and the establishing of labs is hindered by financial and administrative hurdles. As Fab Labs rely heavily on proprietary machine tools, open-source economics provide a promising alternative that mitigates many of the challenges associated with the setting up of Fab Labs. The Open Lab Starter Kit (OLSK) makes use of Open-Source Machine Tools (OSMT) to empower makers to establish so-called open labs. This chapter introduces the OLSK and explains its design philosophy based on open-source principles, in juxtaposition to the global Fab Lab movement. It analyses the OLSK's application of OSMT and how it enables the wide diffusion of digital fabrication tools and technological innovation.

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## 19.2 Fab Labs: Enablers of Technology Emancipation?

The first so-called Fab Lab was founded at the Massachusetts Institute of Technology in 2002 with the aim to make the tools for digital fabrication more widely accessible. As communal manufacturing spaces it is their goal “to allow anyone anywhere to make (almost) anything”, thus making personal manufacturing broadly available (Fablabs.io, o.J.-b). Their standard inventory is an array of mutually compatible and complementary machine tools. At the very least, it typically includes 3-D printers, laser cutters, and milling machines. Their broad and inclusive approach towards manufacturing and their aim to reshape the modes of production towards a grassroots technology emancipation has even resulted in Fab Labs being called the onset of the next industrial revolution (Anderson, 2012). In this, they are also an essential part of the concept of fab cities and enablers for circular economic models (Fab City Hamburg, o.J.). The overall number of Fab Labs has surged in recent years, and there are now more than 1750 labs strewn across 100 countries. However, there are great geographical differences in their distribution, and many more labs have been set up in countries of the global north than the global south (Fablabs.io, o.J.-a). The main reasons for this are challenges associated with the typical Fab Lab inventory. Nearly all machines included in the list of recommended standard lab inventory are proprietary machine tools that are almost exclusively produced in industrialized countries. In total, they typically cost well over USD 100,000 (Békés & Harasztosi, 2020; RepRap, 2022). As a result, setting up the machine inventory of a Fab Lab in the global south is much more expensive than in the global north, not only due to the comparatively higher buying price in relation to the average purchasing power but also because of the additional costs associated with transporting and importing them (including customs taxes, shipping costs, and opportunity costs due to administrative hurdles and time-consuming processes). Moreover, the use and maintenance of imported machine tools may be associated with additional inconveniences over the course of their use when repairs and maintenance works are needed, and spare parts or adequately trained personnel are not readily available.

These combined challenges make the setting up of Fab Labs difficult and expensive endeavors. Especially in contexts with less abundantly available financial resources, the Fab Labs’ reliance on proprietary machine tools can prove to be a serious obstacle to the establishing of labs. This hinders the global diffusion of digital fabrication technologies. Consequently, this exacerbates the uneven distribution of these technologies and results in an even more disparate access to manufacturing technologies across the globe. As a result, new Fab Labs are typically established in areas where resources are readily available and access to manufacturing technologies is not difficult. This further aggravates issues of unequal technology access, as those in need of them the most cannot get access to them with the help of Fab Labs. This is a predicament as it contradicts one of the key aims of the Fab Lab movement: to provide universal and equitable accessibility to the means of production. In fact, Fab Labs do not truly enable anyone to produce almost anything because their spatial distribution is limited, and they are simply not accessible to everybody. This in fact increases the discrepancy in technology access and availability of modern means of manufacturing between the global north and the global south which Fab Labs aim to mitigate.

## 19.3 Enhancing Fab Labs with Open-Source Machine Tools

The Open Lab Starter Kit (OLSK) is a project that aims to meet these challenges. Since early 2021, it is being developed in a research project at the laboratory for manufacturing technology of the Helmut Schmidt University in Hamburg, Germany, in collaboration with InMachines Ingrassia GmbH, a startup focused on open-source machine tools development (Fab City Hamburg, o.J.). The project consists of three one-year development cycles during which a total of eight machines are designed. During each cycle, one prototype of each machine is manufactured and tested. The development cycles follow an incremental and iterative approach in which each subsequent prototype is built based on the analysis and capabilities of the previous cycle's prototype. Each new prototype therefore offers additional or improved features.

The OLSK generally follows the Fab Lab idea in that it aims to establish public spaces for personal manufacturing that make digital production tools accessible to anyone. However, instead of simply listing proprietary machine tools as recommended inventory, the OLSK is an online repository with detailed plans and instructions on how these machines can be built by the users themselves (The Fab Foundation, 2022). The central concept of the OLSK is therefore based on open-source principles applied to tangible artifacts, in this case Open-Source Machine Tools (OSMT). OSMT are a subcategory of Open-Source Hardware (OSH) that encompasses all machines which enable the manufacturing of products, and which are made freely available online for anyone to be replicated, modified, studied, or sold (Omer et al., 2022). In recent years, OSH in general and especially OSMT have seen a surge in popularity, resulting in an abundance of designs scattered across the internet. However, their sheer volume and the vast number of OSH repositories makes it challenging to locate individual machine designs. Moreover, as there is yet a lack of proper standardization and certification guidelines, there exists a significant variation in design quality and documentation. Anyone can upload an OSMT design without assuming any responsibility for its replicability, quality, or safety. This has led to the release of poorly designed projects with insufficient or faulty instructions. For example, manufacturing guides are commonly missing in many open-source projects published online. Manufacturing processes to produce machine components that are not bought off the shelf require specific and accurate machine settings, jigs, and measuring tools. When these manufacturing processes are not described to the OSMT user, the manufactured parts can lack accuracy or might even be produced in completely wrong dimensions. This can create further problems in the subsequent assembly process and may render machine designs either not replicable or even outright dangerous.

The OLSK project aims to address these shortcomings by developing complete, easily replicable machine designs that fulfil high safety standards, and then compiling them in a single online repository. The OLSK follows a comprehensive approach to project documentation with detailed user and assembly guides, tutorials, and troubleshooting assistance (see Fig. 19.1). Additionally, the project publishes the CAD files for each machine design. This way, users can make a wide range of modifications to the machines to account for differences in resource availability and manufacturing technologies. Through this, the machines can also be tailored to meet the diverse budget and spatial constraints of each individual user. By creating a platform that allows for easy replication and modification of a range of machine designs, the OLSK drastically facilitates the access to the inventory needed to establish laboratories for digital fabrication (Omer, 2021).

Similar to the Fab Lab inventory, the OLSK repository is designed to form an ecosystem of eight complementary and versatile machines that allow for the production of a wide range of products (see Table 19.1 and Fig. 19.2).

The machines in the OLSK repository can theoretically be accessed by anyone from anywhere in the world and allow for the setting up of so-called open labs – fabrication laboratories that are set up with OSMT. The machines included in the OLSK repository have been intentionally selected to fulfil the digital fabrication training requirements of Fab Labs aimed at equipping users with hands-on experience in rapid prototyping. Open labs therefore offer similar capabilities and learning opportunities as Fab Labs.

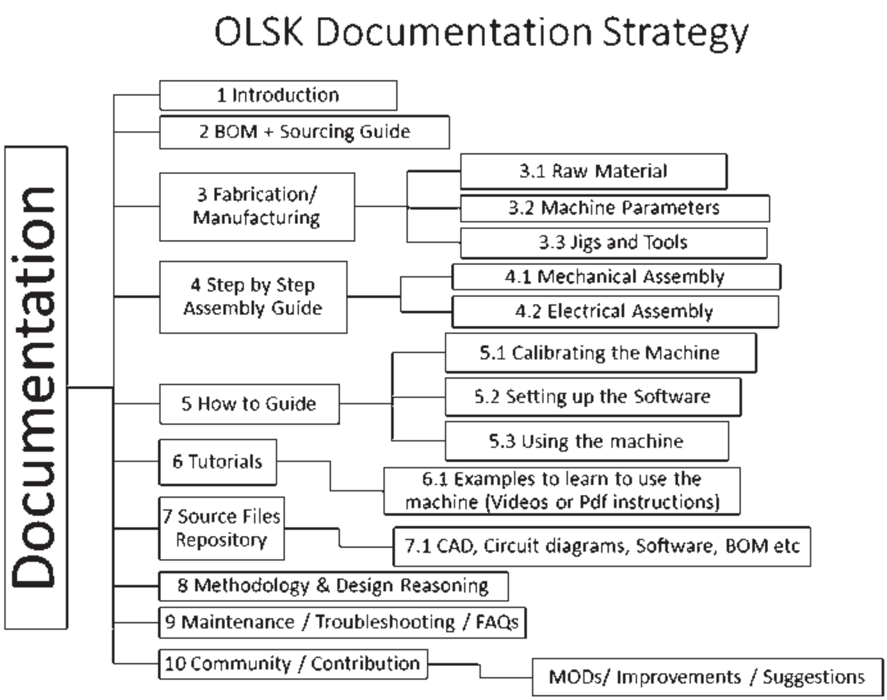


**Fig. 19.1** Overview of the Open Lab Starter Kit documentation strategy

**Table 19.1** The Open Lab Starter Kit machines' technical specifications

| OLSK machine | Technology | Working area (mm) | Materials |
|---|---|---|---|
| Small 3-D printer | FDM additive manufacturing | 200 × 200 × 200 | PLA, ABS, and other common FDM filaments |
| Large 3-D printer | | 1000 × 1000 × 1000 | |
| Small laser cutter | Laser-cutting subtractive manufacturing | 600 × 400 | Sheets of plywood, acrylic, cardboard, paper, etc. |
| Large laser cutter | | 1000 × 700 | |
| Small CNC | CNC milling subtractive manufacturing | 600 × 400 × 150 | Aluminum, wood/plywood, PCBs copper sheet, etc. |
| Large CNC | | 2500 × 1250 × 300 | |
| 3-D scanner | 3-D scanning | 300 × 300 × 300 | – |
| Vinyl cutter | Blade-cutting | 300 | Vinyl stickers, maskings, etc. |

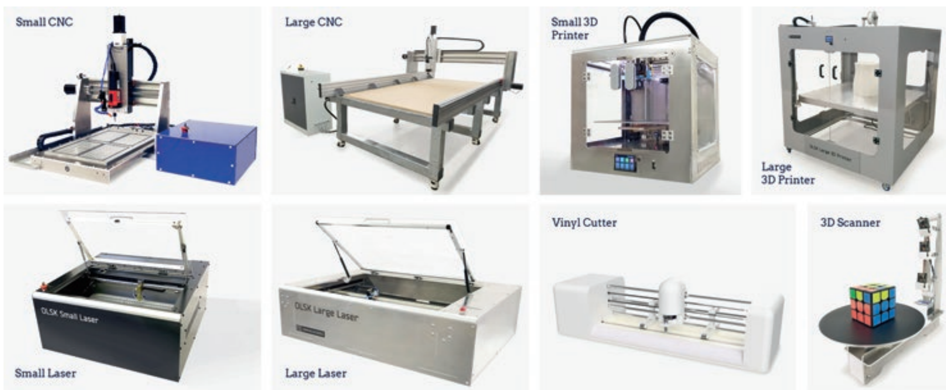


**Fig. 19.2** Overview of the Open Lab Starter Kit machines

To increase the safety and replicability of the machines in the OLSK repository, the machine tool designs follow industrial best practices for design for manufacturing and design for assembly. All OLSK machines can be replicated with the standard Fab Lab inventory and do not require heavy industrial production techniques. They are designed to be comparatively easy to build with minimal room for mistakes. Specifically, the machine designs use the poka-yoke approach by relying on assemblies and sub-assemblies that can only be put together in a single way. This allows for easy and fail-safe assembly which helps prevent user errors. The OLSK machines are built from a mix of ready-made and custom parts, whereas the former are selected according to their ease of sourceability in as many countries as possible; the latter can be built using either the machines of the Fab Lab inventory or standard hand tools. Existing open labs can therefore produce the OLSK machine ecosystem, and the labs are thus self-replicating. In this respect, the OLSK constitutes an advancement towards making Fab Labs instead of buying them, as is the case with conventional Fab Labs.

The building instructions furthermore primarily rely on diagrams and schematic figures with little written information to reduce language barriers in the building process (see Fig. 19.3). By emulating the successes of the picture-based manuals of companies such as

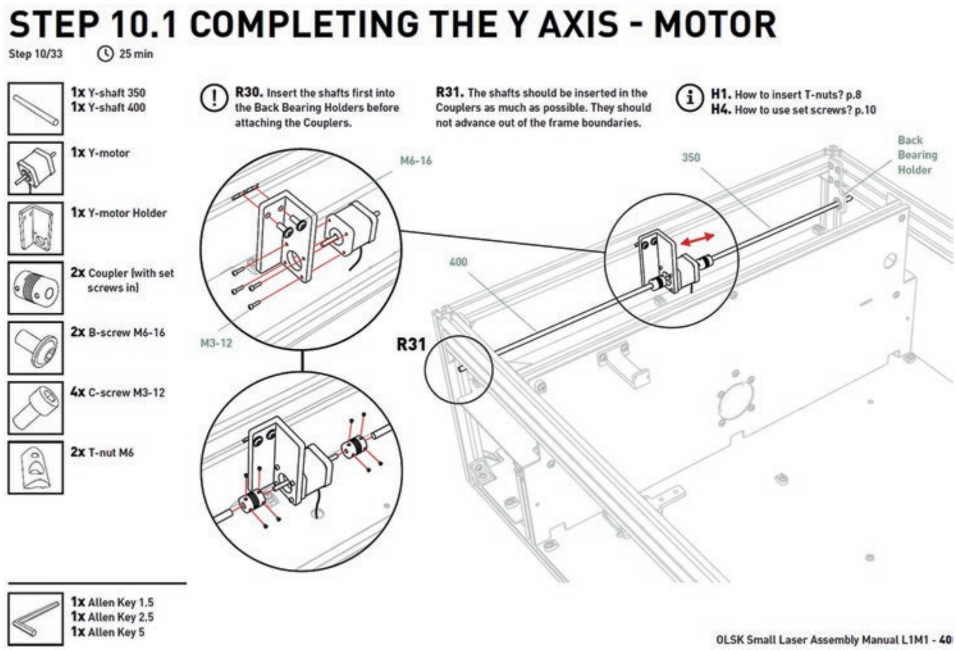


**Fig. 19.3** Excerpt of the build manual of an open-source laser cutter from the Open Lab Starter Kit

IKEA and LEGO, the instructions are kept as simple and unambiguous for the user as possible. This eliminates potential errors and makes the machine designs safely replicable for users without previous machine-building knowledge. Additionally, the building process equips users with in-depth knowledge about their machines, thus facilitating the repair and maintenance processes.

By basing the OLSK on open-source principles, it is able to drastically accelerate the spread of open labs and rapidly increase access to manufacturing technologies, thus inspiring innovation (Teece, 2017). While there have been other initiatives for the development of a portfolio of open-source machines similar to the OLSK, they have a comparatively limited scope and do not reach the broad capabilities offered by the OLSK. For instance, the RepRap Project focuses on developing different types of open-source 3-D printers that can replicate themselves (RepRap, 2022). Another project called Fabricatable Machines mainly makes use of CNC machine tools that can be replicated in a Fab Lab setting (Fossdal et al., 2020). However, both projects focus on a single type of machine whereas the OLSK's open labs offer a small ecosystem of five different types of machine tools with a broader range of digital fabrication technologies. The OLSK therefore enables users to access similar technological capabilities as Fab Labs while providing the benefits associated with open-source economics.

However, the use of OSMT is also associated with several challenges that will require further research and targeted action to be resolved. This includes difficulties in designing machines that are universally adaptable, as the lack of access to standardized machine elements in contexts of constrained resources can hinder the replication process even if most parts can be built from scratch. Moreover, due to the lack of open-source automatic documentation tools, the process of documenting the OLSK machines is difficult to sync with design changes. This leads to challenges in including changes and improvements in the machine design in the documentation. Another challenge is the fact that, while the OLSK repository aims to make its machine designs replicable by anyone without previous engineering domain knowledge, certain levels of skill and experience are required nonetheless for precise, accurate, and safe machine tools.

## 19.4 Conclusion

Compared to the conventional Fab Lab approach, the OLSK's adoption of open-source principles has a few advantages. On the one hand, the machines are designed to be easily replicable for almost anyone, which drastically lowers the thresholds for machine tool access by eliminating the need to import them and making them widely accessible. This makes OSMT much cheaper compared to proprietary machine tools and resolves the need for long and complicated shipping processes. The machines included in the OLSK repository are furthermore highly modifiable and can be adapted to different circumstances and resource constraints. On the other hand, self-building the inventory of the open labs brings the additional advantage that users gain a heightened sense of ownership and a thorough understanding of the machines and are therefore better able and more likely to do maintenance and repair works themselves. As the OLSK further aims to prevent safety concerns by eliminating design flaws and ambiguous instructions, the approach of the open labs constitutes a pioneering alternative to conventional Fab Labs. While some challenges associated with the use of OSMT persist, the OLSK's approach has the potential to drastically increase the global number of Fab Labs and lead to their more equitable spatial distribution. These open labs will likely serve as tools to inspire the innovation of countless derivative technologies whose inventions are made possible by the technical infrastructure provided by the OLSK, and they will further contribute to the spread of fab cities by localizing production and enabling a circular economy.

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# Open and Circular Value Creation in the Open Microfactory

20

Michel Langhammer, Lennart Hildebrandt, Henrik Seeber, Manuel Moritz and Tobias Redlich

## 20.1 Introduction

Recent environmental, economic, and societal instabilities such as the climate crisis, disrupted supply chains, and the rising global social inequality pose new challenges, especially for today's global production systems. Factories as places of value creation through processing materials to components and products with the use of production means, information, and energy, contribute significantly to the consumption of earth resources (Marchi, 2022). Set climate goals are unlikely to be achieved and carbon dioxide ($CO_2$) concentration which represents a control parameter of the planetary boundary framework is already in its limit range with the forecast of an increasing risk (Rockström et al., 2009; NOOA-climate.gov, n.d.). $CO_2$ emissions, particularly, depend directly or indirectly on the global production networks and their, so far, unsustainable operations. Furthermore, the UN Sustainable Development Goals (SDGs) address the need for a transition in production systems with goal 12 "Responsible Consumption and Production":

> Goal 12 is about ensuring sustainable consumption and production patterns which is key to sustain the livelihoods of current and future generations. Unsustainable patterns of consumption and production are root causes of the triple planetary crises of climate change, biodiversity loss and pollution. These crises, and related environmental degradation, threaten human well-being and achievement of the Sustainable Development Goals. (United Nations Sustainable Development)

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Thus, there is a need of rethinking our current value creation system, especially, of factories as its elementary components. New concepts and models should consider existing industrial production infrastructure as well as new bottom-up production approaches as seen in the maker movement where new innovative methods are designed and show great potential for adapting our current way of consumption and production (Hildebrandt et al., 2022).

Concepts proposed in the literature for sustainable factory units are tightly linked to the concepts of circular, sustainable, and changeable manufacturing systems as a superordinate system layout (Acerbi & Taisch, 2020). Concepts of Industry 4.0 and Cyber-Physical Production Systems (CPPS) make use of the digital sphere for data processing, monitoring, automation, and validating actions of adoption (Schmitt et al., 2017; Hästbacka et al., 2022). These approaches present possibilities to keep the value creation cycles geographically minimal while, at the same time, maximizing the energy and material efficiency using data-driven monitoring and control.

Most production systems are based either on small workshops, labor-intensive processes with low output levels, or on large factories with standardized, capital-intensive processes and high output levels. These poles leave a large gap between very low production volumes (maximum of hundreds of units) and very high production volumes (millions of units) (Montes & Olleros, 2019). On the factory level, microfactory concepts with existing subsets of urban and local microfactory are therefore presented (Hildebrandt et al., 2020; Herrmann et al., 2020). Open Labs contribute to citizen education, innovation, and peer-to-peer production of local, bottom-up based value creation from which sustainable, socially fair and resilient solutions emerge (Redlich et al., 2015). Especially with open-source methods, new forms of collaboration, community-based and bottom-up approaches both on a socio-economical and technical level take place (Bonvoisin et al., 2020; Omer et al., 2022; Directorate-General for Communications Network et al., 2021).

The mentioned concepts in industrial production continue to leave out the social factor in terms of participation of locally influenced actors. Also, the criteria of optimizing production processes are dependent on ownership rights of production means and non-transparent decision-making structures. However, Open Labs and the respective makerspace infrastructure cannot meet the current production demand. They also lack concrete methods for products with higher complexity and quality. Therefore, a technological as well as operational advancement of current Open Lab concepts is required that is oriented towards existing sustainable and circular production strategies by keeping its character of openness, co-creation and collaboration.

The goal is to develop a concept for a microfactory that integrates the current state of the art and best practices from industry. Yet, it should also take methods and technologies of Open Labs, open-source software and hardware into account, leading to a complementary production entity that is locally integrated and provides a contribution to the transition to an open and circular value creation system.

This paper introduces concepts of circular manufacturing, microfactories, Industry 4.0 and open production, then describes the OMF approach and its scope as well as a high-level architecture layout. It closes with a conclusion and discussion for further research.

## 20.2 Theoretical Background

**Circular and Changeable Manufacturing**

Circular manufacturing is described as an overall system framework for closing the loop of product life cycles through multiple uses of components and materials, preferably in their original form. Therefore, a systematic perspective on the phases of production planning, supply-chain configuration, manufacturing, delivery as well as use, recovery and reuse is necessary: not only on the physical product and production level but also on the service level which includes the provision of complementary product-service systems. The aim of this resource circulation is to reduce the total amount of resource use while simultaneously raising the environmental efficiency of resource usage (Kimura, 2012; Shi, 2021).

A systematic multi-method model and simulation approach introduced by Roci et al. (2022) provides different layers of modeling including agent-based, discrete-event and dynamic system model domains for each stakeholder of a value creation system such as customers, service providers, manufacturers, and recyclers. For a manufacturer stakeholder, a machine operator, for instance, represents one type of agent with the knowledge and the skills to participate and interact in the circular manufacturing system. The dynamic and discrete-event model types are more technical process-centric methods to model process behavior over time or asynchronously occurring events like a machine fault or finished process step. The management of data is described in the context of an information system (Roci et al., 2022).

Complementary to the circular manufacturing system, ElMaraghy und Wiendahl (2009) described changeable manufacturing systems with their capability of flexibility and changeability for a production of a higher product spectrum. Changeable manufacturing systems accomplish early and foresighted economically feasible adjustments to its structures and processes on all levels. A first set of changeable manufacturing characteristics is: changeover ability on process and machine-cell level to manufacture ad-hoc different variants; flexibility on a system level to manufacture different products by reprogramming, re-scheduling or re-routing; reconfigurability on a system level to prepare for changing volumes of new products and returned, used products by adding, removing or changing modules in the system; and transformability to significantly change the manufacturing structure to produce an entirely different product type (Brunoe et al., 2018, 2019).

**Urban Factory and Microfactory**

The VDI guideline 5200 defines a factory as a “place where value creation takes place through the division of production labor of industrial goods using production factors.” The production factors are the required operating resources, materials, energy, information, and personnel. Factories are referred to as socio-technical systems due to the complex interplay of production factors (VDI, 2011).

A specific factory design for urban space is the Urban Factory (UF), which is defined as a factory in an urban environment that actively uses the characteristics of its surroundings. The UF has a minimal negative ecological impact on its surrounding area by minimizing emissions of, e.g., sound, smell and traffic load, while simultaneously positively influencing the local economy by increasing the demand for jobs, social-economic interaction, and innovation fostered by an urban factory (Herrmann et al., 2014). As a first typology regarding characteristics, potentials, and challenges of transition zones, where an urban factory is embedded in an existing socio-ecological environment, the concept of ecotones for sustainable value-creation is presented by Juraschek et al. (2018).

The term of a microfactory in contradiction to older publications does not refer to minimizing the machining size and matching it to the part size of a micro-part-industry (Herrmann et al., 2020). Instead, it refers to the concept of highly modular, flexible and automated production facilities with a relatively low spatial footprint (Hildebrandt et al., 2020). Montes und Olleros (2019) describe further characteristics of how microfactories can stimulate local and demand-driven innovation for the need of local demand-driven fabrication as well as the central role of digital technologies with digital sensing, simulation, and the use of computer-aided design and manufacturing software in microfactories.

**Cyber-Physical Production Systems and the Industrial Internet of Things**

For data-based circular economy approaches, data-driven circular manufacturing system models need to be linked to physical infrastructure entities like a factory. The term Cyber-Physical Systems (CPS) was introduced by Helen Gill at the National Science Foundation workshop in 2006 (Cyber-Physical Systems Virtual Organization, n.d.). It describes the integration of computer calculation in physical processes, influencing other physical processes, providing sensory feedback signals, and thus connecting the physical and information technology world. CPS arose as a result of the networking and integration of embedded systems and application systems. Schmitt et al. (2017) summarize a CPS as a physical system with data storage, data processing, and extensive communication interface features which increase the level of local system intelligence.

With a special focus on production-related processes, the term Cyber-Physical Production Systems (CPPS) evolved and considers the product, the production and the production system. It provides the opportunity to allow methods for a Plug-and-Produce capability. A CPPS supports autonomous self-monitoring and helps receive a self-organizing adaptable production. Standardization and modularization play an essential role as they allow a network-wide connection of entities within a CPPS (Schmitt et al., 2017). A CPPS can exist out of more CP(P)S entities connected in a hierarchical, decentralized, or distributed communication topology with several subsystems, making it a system inside a system (SoS) model type comprising physical processes, models of software and computation frameworks and networks (Putnik et al., 2019). CPPS includes, thereby, the current industry concepts and applications in the field of Industrial Internet of Things (IIoT) or Industry 4.0.

With CPPS entities, the use of factory automation and data management technology is crucial. Therefore, Raptis et al. (2019) and Brecher et al. (2021) give a comprehensive overview of key technologies and services which enable the potential of networked industrial systems reflected on the existing industrial automation pyramid model. For this paper, the most relevant fields rely on Machine-to-Machine (M2M) communication, automated robots (which includes computer numerical controlled (CNC) machines), (automated) assembly lines and (wireless) networked control systems (WNCS) on the control and periphery layer which is directly connected to the given physical production processes in the CPPS entity. On the supervisory and data acquisition layer, based above the control layer, with more data-centric, service-oriented methods, there are job scheduling, decision-making, anomaly detection and fault diagnoses as well as energy management. In the multi-entity networked cloud-based layer, technologies like big data analytics as well as ontology and semantic-based methods provide machine-learning capabilities in defined use-cases and data spaces.

**Open Production, Open Labs and Open-Source Hardware**

The concept of open production comprises comprehensive value creation systematics, describing new forms of value creation in a bottom-up economy in which collaborative, distributed and self-organized interaction between individuals or organizations takes place during all phases of value creation. The principle of openness, which describes the open interaction of subcomponents within this system, is an essential element of the open production framework (Redlich & Wulfsberg, 2011). Openness in terms of knowledge and information components is developed under the terms of free and open-source software (FOSS) and open-source hardware (OSH). The Open Source Hardware Association (OSHWA) defines open-source hardware as follows: "Open-source hardware is hardware whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design" (OSHWA, 2022).

Openness in terms of production spaces is represented in Fab and Open Labs. These are places where access to production infrastructure like digitally controlled machine tools, e.g., 3D printers, laser cutters and CNC mills, is provided for the local community. This access allows them to learn about and innovate new product designs, prototyping and production methods through bottom-up and problem-oriented practice. Fab and Open Labs offer a space for self-organized and collaboration-oriented projects and contribute to an increasing participation of the local community in value-creation processes (Basmer-Birkenfeld et al., 2015). Redlich et al. (2016) characterize a new production system on an Open Lab microfactory level with robustness and wear-resistance, minimal capital and operating costs, low precision, flexibility and adaptability, standardized machine parts and products, basic raw materials, small spaces, and high movability. In recent research, Buxbaum-Conradi et al. (2022) describe an urban living lab approach in the context of open, distributed manufacturing (ODM) executing cosmo-local peer-production.

## 20.3 The Open Microfactory Concept

The developed concept of OMF shall provide a first basis for a model-based system design of microfactories in the context of open and circular value creation. The focus is on the ability to provide a data-driven factory entity in a local production network. All capabilities required for circular fabrication shall be covered with an additional focus on end-of-life product handling, material recycling, and reconfiguration of OMF settings as well as data monitoring.

**Context and Scope**

The goal is a regenerative circular value creation system with minimal global dependencies regarding the flow of goods, material, and energy. The OMF concept functions as a complementary component to the existing industrial as well as Open Lab infrastructure. Therefore, Hildebrandt et al. (2020) introduced a hybrid concept, a space between the maker movement and industrial production. The space spans across four dimensions: production depth, technical capabilities, and production quantity and quality. At one pole, industrial production with a high number of quantities, quality as well as high production depth and high-end technical capabilities. The other pole marks makerspaces with low-quantity, low-quality, low-production depth, and simple digitally controlled machines and hand tools.

The concept of OMF introduces a hybrid manufacturing facility that aims to fill the gap between makerspaces and industrial production to allow medium-sized production volumes and product complexity, medium- to high-quality standards, a medium production depth and a medium to high capability spectrum. In addition, the OMF can be set up either as a new building or integrated into existing infrastructures, with a thereby minimally invasive and effortless construction. By integrating into existing spatial structures, a maximum symbiosis with external systems shall be achieved.

Due to its high modularity and flexibility, production processes in the OMF should be designed according to the principle of elementarization (Redlich et al., 2018). Elementarization describes the decomposition of the production process and system into elementaries, i.e., into the smallest sections of product creation with a low complexity. These production elements are designed as simple, self-centering systems that can be operated intuitively and are highly robust due to a minimal need for control. The connectivity between the workpiece and the production elementary is designed to allow for the creation of ad-hoc machining spaces. The elementaries are encapsulated systems, this procedure enables them to be combined in any way for process chains.

**Demand-Driven and Service-Oriented Operation**

The OMF is intended to produce according to local demand, to which it then allocates its available resources. Therefore, the OMF is providing manufacturing and machine-as-a-service capabilities to any entity in the local value creation network, e.g., individuals, organizations, businesses, or municipalities on peer-to-peer (P2P) level. A service can be offered or requested at machine level if production capability of one machine workstation is sufficient for the request. As soon as a linking of several workstations is required for a given service request, a manufacturing-as-a service offer will be generated. As an additional service to local customers, the configuration of the OMF for new product requests is provided, unless it is not completely automated. The OMF is integrated into the value creation phases of design configuration, production, manufacturing, recycling, repair, and disassembly. If no knowledge and skill is available for the condition of operating the OMF, an Open Lab or Fab Lab for training and building the necessary skills is to be selected as an educational location in the local open production network.

**CPPS Classification**

The OMF is classified as a CPPS entity. Thus, the OMF has physical production capabilities in the form of flexible machine, recycling, assembly, and disassembly stations, as well as data processing and communication interfaces covered in an OMF data platform. The individual OMF stations represent a CPPS entity in the OMF. Through the classification of OMF as a CPPS entity, the OMF itself can be modeled and simulated to analyze its environmental influences. The following high-level architecture model in Fig. 20.1 shows the designed OMF with its CPPS entities, their network topology and first set of process flows.

The individual CPPS entities contained in the OMF are referred to as stations. Each station consists of a *hardware layer* which presents the interface to its physical mechanical, thermal or electrical processes. It reflects the physical layer of the CPS concept. The *automation layer* contains the embedded hardware and software components as well as sensors and actuators monitoring and controlling the hardware as well as its underlying physical processes in real time cycles. It reflects the data processing and data storage functions of the CPS concept. The *communication layer* contains an extensive communication interface to realize different protocol standards with different physical transmission methods to exchange product and production related datasets. It reflects the communication interface of the CPS concept. Each OMF station or entity exists 1 to n times in the OMF, and each OMF exists 1 to n times in the local open production network.

To fulfill the need for an end-of-life product handling as well as a high integration of automation, the OMF provides a first set of defined stations: The *material & recycling station* describes an OMF's material input and storage unit with an optional recycling unit to feed-in recyclable material in the production process. It represents the OMF's general material input station. The *flexible machine station* consists of a machine tool unit with a first set of a defined technical capability spectrum. The determination of a first set of technical

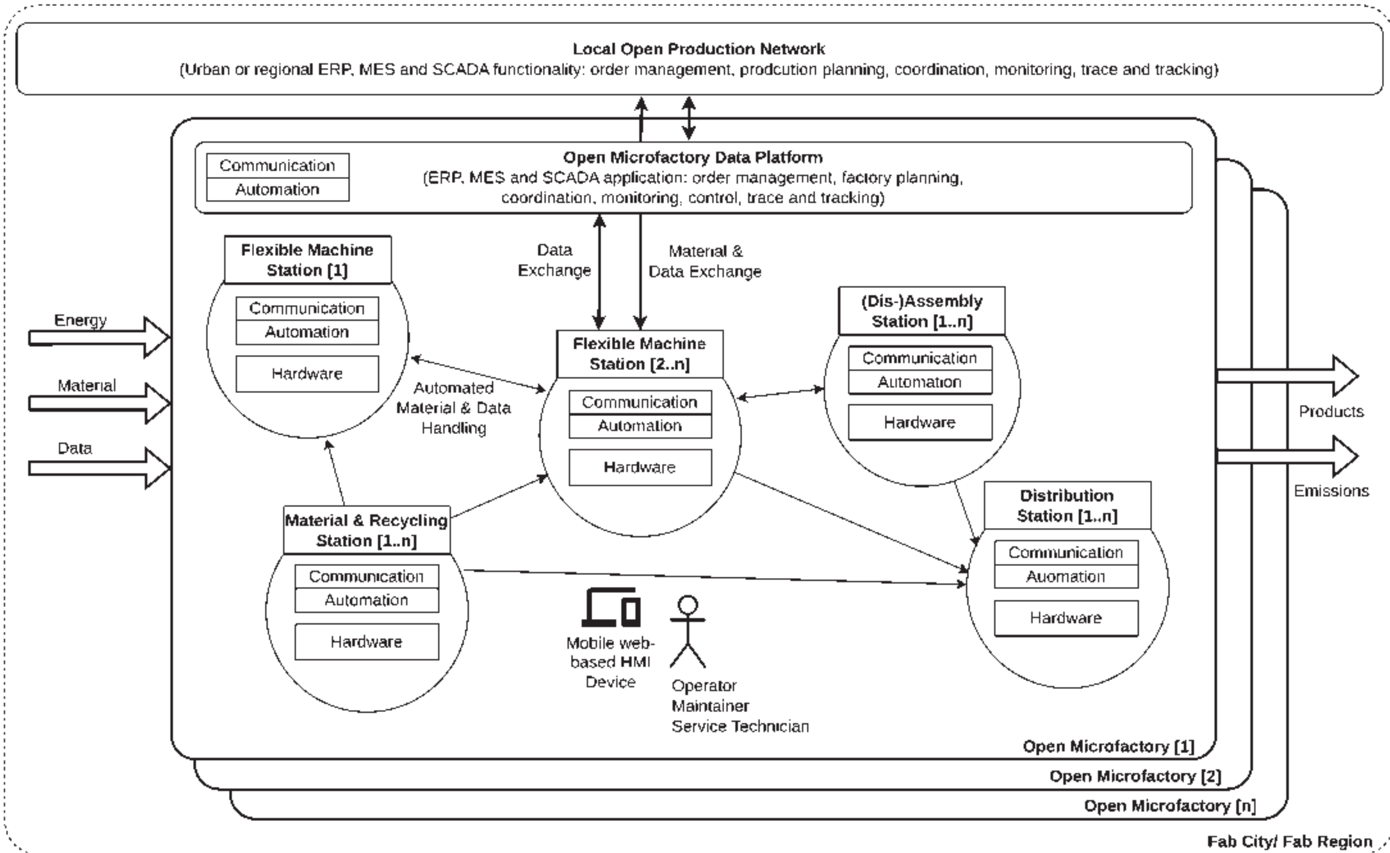


**Fig. 20.1** Representation of a high-level system architecture for Open Microfactory (OMF) in a local open production network

**Table 20.1** Description of identified technical machine features for the Open Microfactory

| Technical machine feature | Description (the capability of the machine …) |
|---|---|
| Digitalization | … to be used in networked process chains with other machines and digital entities in a digital connected and automated environment |
| Modularity | … to be used in a changing process flow without friction |
| Processing speed | … to finish a certain manufacturing task as fast as possible |
| Setup effort | … to be set up for a manufacturing task with minimal effort |
| Machine hour rate | … to manufacture as efficient as possible (per hour) |
| Material diversity | … to process different materials |
| Technical quality of the process | … to produce products with a given quality |
| Data compatibility | … to work with different standardized data formats |
| Technical degree of freedom | … to process materials with a high degree of axial freedom |
| Service intervals | … to have low service rates |
| Service life | … to have a high durability and low downtimes |
| Useable working space | … to have a high workable width, length and height |
| Investment and operation cost | … to have low initial and operational costs |
| Technical safety features | … to have integrated safety features to prevent injury |
| Automation capability | … to work with digital data formats to conduct manufacturing tasks in real-time control loops |
| Size | … to be as small as possible |
| Weight | … to be as light as possible |
| Energy and Material Efficiency | … to be as clean as possible, regarding vapors, metal powder, $CO_2$ emission (derived from overall energy consumption), etc. |
| Noise- and Vibration emission | … to be as silent as possible |
| Visibility of processes | … to have a visible process |
| Open-source readiness | … to use open-source hardware and software components |

machine functions has been carried out in an expert workshop using the delphi method. Table 20.1 shows an initial list of the identified technical functions that a machine in the OMF should have.

The feature list shows a large overlap with existing industrial machine features. One significant difference lies in the feature of open-source readiness. In addition to the machine tool unit, it provides a material in- and outfeed block with integrated pre- and post-processing and quality inspection. This station describes the manufacturing of material and components and its processing according to a configurable specification.

The *(dis-)assembly station* is used for the assembly of manufactured and purchased sub-components to a functional sub-module or final product. Products and modules that have already been assembled can also be disassembled in this station in order to reuse the contained functional components or to repair components that are no longer functional.

In the *distribution station*, the components manufactured and assembled in the OMF are prepared for the next value-added step outside the OMF. This normally includes packaging and transfer to the next logistic process.

Each station is physically interlinked via *automated material handling systems* through handling robotics and automated guided vehicle (AGV) technologies. Standardized transport interfaces are to be provided for this purpose. The spatial arrangement of the different stations is not considered in the concept since a flexible spatial repositioning of the stations should be given as far as possible in the given space.

Each OMF runs its own local *data platform*. It is used for an end-to-end networking of all existing sub-entities. It runs applications or digital services in the domain of order management, resource planning, process monitoring, in general services for efficiently orchestrating all entities as well as trace and tracking of material and energy flows. The network topology is aimed at a maximally distributed structure with P2P communication mechanism through all entities. This P2P capability is also given outside the OMF boundary. This means that one OMF station is able to exchange data with different OMFs or directly with their respective OMF stations. For example, can "Flexible Machine Station 1" of "OMF 1" exchange data and material with "Assembly Station 1" of "OMF 3" in the local production network, or "OMF 2" can exchange data and material with "OMF 3". This allows all entities to be virtually connected to each other.

When applicable and possible, it is targeted to use *OSH factory equipment* as well as FOSS engineering and application tools. With FOSS, the primary goal is to increase ad-hoc configurability to required manufacturing and assembly settings. This is otherwise primarily given by open Application Programmable Interfaces (open APIs) of different computer-aided lifecycle management tools such as computer-aided design (CAD), manufacturing (CAM) or quality (CAQ). A maximum degree of interoperability is necessary for consistent data management and reduced redundancy in data exchange between product design parameters, production planning settings and manufacturing execution platform up to the machine control level. Using FOSS, it is aimed to have optimal continuous integration of new factory and machine configurations. The use of OSH equipment in form of automation components such as embedded control systems, sensors, actuators or entire machine units, as described in the concept of open-source machine tools (OSMT) by Omer and colleagues (2022), gives the OMF a maximum amount of autonomy in its strategic and operational decisions. OSH factory equipment provides the local community with expandable service options around the equipment in terms of operation, maintenance, retrofitting or optimization services. The OMF itself represents an OSH entity, similar to the Open Lab concept where its blueprints, used equipment and configuration settings are openly accessible so that they can be replicated, re-designed and modified in a distributed manner adapted to local requirements.

**Open Production Data**

The OMF intends to provide digitally open access to defined production process data which are of particular importance in the context of planetary boundary control parameters. The openly accessible datasets can be used as model and simulation-based optimizations in regards to energy and resource efficiency, and thus measure and evaluate decided optimization methods. Through the distributed development of optimized process configurations, adaptation cycles can be reduced. In addition, open data can be used as a transparency tool and include local communities in the decision-making process of new OMF setups like the principle of community monitoring described by Danielsen et al. (2022), which could be adapted to the OMF datasets. Through the open exchange of data between different entities in the entire local value creation network, the decision horizon for supply-chain moves can be expanded and help to increase the overall model sensitivity of the local circular manufacturing model.

## 20.4 Conclusion and Outlook

Factories as places of value creation make a significant contribution to prosperity, while they, at the same time, contribute to climate-damaging emissions. Thus, a conversion of these production facilities is of great importance. The OMF functions as an open production entity with minimal spatial and ecological footprint, and a minimal invasive integration in new or existing infrastructure. It processes a minimal amount of local resources to fulfill the local demand of production with sustainable production patterns and data-in-data-out capability as required in the SDG goal 12 and the Fab City concept.

The presented concept of an OMF shows a possibility to implement a circular value creation system with the help of a small-scaled, highly automated, open-source designed factory unit. Therein, technologies from industrial manufacturing, as well as modeling methods from the field of CPS, Industry 4.0 and circular manufacturing are considered. Main features are the integration of highly automated manufacturing sub-stations as well as data management systems, which are based on a distributed communication topology to allow for a P2P data exchange. The concept of open production is taken into account with Open Labs as places of co-creating new circular product design and production methods as well as FOSS and OSH as commons-based equipment units for the OMF to provide maximal autonomy and self-organization.

For the use of data-based methods for the conversion to a circular economy production, the monitoring of process data, especially of environmentally harmful emissions, is necessary. In order to not exceed the limits of defined planetary boundary variables, and to be able to make decisions that influence these variables transparently, the concept of OMF describes a disclosure of these process data, according to the principle of community monitoring. This ensures that the direct influences on the environment can be considered by the community that is directly influenced by the OMF, thus a commons-based organization can be developed around the OMF.

The following discussion points should be listed for consideration in the further development of the OMF concept:

- Which degree of automation is necessary, considering that any deployed automation technology requires development, maintenance, and refurbishment?
- Which degree of openness regarding open data is necessary and helpful? Can the disclosure of production data add value in terms of material and energy consumption reduction? How can we ensure that there is no blaming of OMF and its operation but a rational evaluation based on given environmental data?
- How can the OMF be operated in a commons-based mode? How can the development and design of the described services be community-based? How can a transfer of methods developed in Open Labs be transferred to and adapted for the OMF?

These questions should be further illuminated and quantitatively and qualitatively researched.

The OMF concept will be tested in the next step by the authors with a concrete set of production capabilities to measure the possibilities of the functionalities described in this approach and their impact and their contribution to the goals of the SDGs, the transition to a circular economy and the compliance with the planetary boundary variables, so that our value creation model can be made regenerative and sustainable.

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# 21 Local Production Networks of SMEs: The Future of Producing Locally?

Julia Christina Markert and Pascal Krenz

## 21.1 Introduction

In 2023, the awareness of ongoing crises is heightened after living through a pandemic, product shortages and continuously more worrying climate events. The past few years have demonstrated just how dependent we are on global value chains but also how much of a liability and risk they can be. One way to alleviate this dependency would be to produce goods locally instead of transporting them over long distances worldwide. A structural change like this, however, faces serious obstacles and problems, especially since outsourcing and globalization, which really took off only about thirty years ago, are by now rooted deeply in the industry and, in most aspects, stand in direct opposition to local production, even though outsourcing efforts have slowed down in more recent years (Matt et al., 2015).

Nonetheless, initiatives and concepts such as Fab City, Urban Production, the maker scene, etc. have been on the rise, creating an awareness of the possibilities and opportunities of manufacturing locally in open/shared workshops (Prendeville et al., 2016). Local production, however, can take on many different forms, one of which is the cooperation of local craftsmen and other local enterprises, which is another type of production that has a lot of potential but has seemingly not generated as much attention. These micro, small and medium-sized enterprises (SME) have often always remained local, with many businesses being family-owned (Wolter & Sauer, 2017, p. 13). Their knowledge and resources could

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play a valuable part in shifting production back to where the products are used and/or consumed.

Therefore, the goal of this chapter is to answer the following three questions:

1. What is the potential of combining local production and production networks?
2. What are the barriers for implementing local production networks?
3. What are the conditions and prerequisites to facilitate the successful creation of local production networks?

The chapter is structured accordingly. After introducing the method, relevant theoretical background information is given on the current status of the implementation of Industry 4.0 in SMEs (Sect. 21.2.1). The reason is that Industry 4.0 seems to be closely related to networks of SMEs, for one because cooperating could make the adaptation of I 4.0 easier by combining resources (Eikebrokk et al., 2021), but using I 4.0 technologies also has the potential to make cooperating in networks more effective (Braun, 2017, p. 21). This paper will also take a closer look at the way SMEs cooperate at the moment and give some information about the network concept 'Virtuelle Fabrik' by Schuh *et al.* (1998) (Sect. 21.2.2). In Sect. 21.3, the three research questions will be answered before a summary and an outlook is provided in Sect. 21.4.

## 21.2 Theoretical Background

For the theoretical background, the current situation of SMEs and Industry 4.0 as well as what constitutes a production network of SMEs are discussed.

### 21.2.1 SMEs and Industry 4.0

Enterprises are usually categorized by their sizes into micro, small, medium-sized and large. The most commonly used categorization criteria are the number of employees and the annual turnover. The scale is less than 10 employees with up to 2 million Euro p.a. in turnover, between 10 and 49 employees with up to 10 million Euro p.a. in turnover, between 50 and 249 employees with up to 50 million Euro p.a. in turnover and more than 250 employees with more than 50 million Euro p.a. in turnover, respectively (Institut für Mittelstandsforschung Bonn, 2023). Literature often focuses either on large enterprises or on the combined subgroups of micro, small and medium-sized enterprises (SME). Micro enterprises, even though they do not appear in the acronym SME, are part of the SME definition of the EU Recommendation 2003/361 of the European Commission (Institut für Mittelstandsforschung Bonn, 2023).

The term Industry 4.0, often shortened to I 4.0, was first coined in Germany at the Hannover fair in 2011 (Drath & Horch, 2014, p. 56). It has since been widely used in reference to the fourth industrial revolution and is characterized by the rise of cyber-physical systems (CPS), the extended use of the internet, i.e., in the Internet of Things, and the interconnectedness as well as digitalization and automation, to mention some of the most prominent technologies (Gilchrist, 2016, p. 195 ff.; Pistorius, 2020, p. 6). In 2016, Gilchrist wrote the following about I 4.0:

> In summary, Industry 4.0 will require the integration of CPS in manufacturing and logistics while introducing the Internet of Things and services in the manufacturing process. This will bring new ways to create value, business models, and downstream services for SME (small medium enterprises). (Gilchrist, 2016, p. 196)

However, as of today, the consensus is still that SMEs have disadvantages compared to large enterprises in terms of the implementation of Industry 4.0 technologies. Table 21.1 shows a selection of obstacles, risks, and difficulties of implementing Industry 4.0 in SMEs.

Overcoming these obstacles and adopting Industry 4.0, however, will provide SMEs with important tools for the future, as, e.g., Weissmann and Wegerer suggest that "dealing with an information-dominated value chain will be vital for the success of a company" (Weissman & Wegerer, 2019, p. 66, own translation). Industry 4.0 technologies are also expected to aid in connecting the actors involved in the production process, leading to an "optimized value stream" (Weissman & Wegerer, 2019, p. 67, own translation).

**Table 21.1** Selection of obstacles, risks, and difficulties of implementing Industry 4.0 in SMEs

| | Obstacle/risk/difficulty | Source/reference |
|---|---|---|
| Resources | "Cost of obtaining money; i.e., the funds for a given investment"<br>"Lack of resources, especially financially" [translated] | Ingaldi and Ulewicz (2020, p. 15)<br>Braun (2017, p. 19) |
| Knowledge | "Lack of know-how" [translated]/"lack of expertise in SMEs" | Braun (2017, p. 19), Moeuf et al. (2020, p. 1396) |
| | "Choosing suitable Industry 4.0 solutions" [translated] | Braun (2017, p. 19) |
| Employees | "Great need for qualification of workers" [translated] | Braun (2017, p. 19) |
| | "Fear of employees that may perceive Industry 4.0 as a means of increasing surveillance of their work" | Moeuf et al. (2020, p. 1396) |
| Strategy and environment | "Narrow product portfolio of SMEs" | Ingaldi and Ulewicz (2020, p. 15) |
| | "Obsolescence of an investment in technology" | Moeuf et al. (2020, p. 1396) |
| | "Short-term strategy of SMEs" | Moeuf et al. (2020, p. 1396) |
| | "Turbulence of the environment" | Ingaldi and Ulewicz (2020, p. 15) |

### 21.2.2 Production Networks of SMEs

Defining the term network in this context is not a trivial matter since different authors often attribute slightly different meanings to the word "network". Additionally, similar terms with closely related or even the same meaning are used as well, most often "cooperation", but occasionally also "co-creation". Schütze suggests using the term "network", as it is the one used most commonly in literature (Schütze, 2009, pp. 9–10). The Observatory of European SMEs created a short but concise definition for a cooperation or a network of SMEs that was also favored by Schütze: "Interaction between independent SMEs for a specific purpose that goes beyond a single task" (KPMG Special Services et al., 2004, pp. 7, 17; Schütze, 2009, p. 10, translation). Such cooperations can be described with the dimensions "goal/objective", "structure" and "dynamic" according to the Observatory of European SMEs (KPMG Special Services et al., 2004, p. 17).

It is not a new idea to have SMEs cooperate in a network. According to a report by the Observatory of European SMEs back in 2004, about 50% of SMEs in Europe – with this number varying depending on the country – were working with other SMEs (KPMG Special Services et al., 2004, p. 7). These networks of limited size are coordinated manually and tend to be rather set/inflexible (KPMG Special Services et al., 2004, p. 7). The focal enterprise coordinating the value chain would then typically be the one with direct customer contact. For instance, a carpenter might always ask the same metalworker and upholsterer for the manufacture of specific parts, or houses might be built with future homeowners often paying someone to coordinate and find all the suitable tradesmen. In fact, Eikebrokk *et al.* have found that "SMEs have very little understanding about how they would go about to initiate a co-creation network" (Eikebrokk et al., 2021, p. 361). Furthermore, the Observatory of European SMEs found that, while a lot of SMEs do cooperate, it is often with very few, rather permanent partners (usually one or two; two-thirds of SMEs have less than seven) that they always keep close contact with (KPMG Special Services et al., 2004, p. 7). This also means that every cooperation partner is tied to significant efforts in keeping up trust and communication. However, especially in smaller enterprises, "the capacity of the organization to coordinate the relationships" (KPMG Special Services et al., 2004, p. 29) plays a significant role in the number of manageable partners: large enterprises usually have specific personnel for the management of the supplier network, something SMEs often do not have the resources for. And while those findings by the Observatory of European SMEs are almost 20 years old, they still seem relevant today, though a slight shift in research interest towards cooperations between SMEs and start-ups should be mentioned.

Nevertheless, a few concepts exist with the goal of creating and governing such networks of autonomous SMEs. One such concept is the 'Virtuelle Fabrik' published in the late 1990s by Schuh, Millarg and Göransson (Schuh et al., 1998). As was done by Katzy and Crowston, the German term 'Virtuelle Fabrik' will be used in this paper (Katzy & Crowston, 2008). In contrast, the direct translation into English, 'virtual factory', is used for two scenarios, one being in the sense of Schuh *et al.*, as described below, the other being “a concept of executing manufacturing processes in computers as well as in the real world” (Onosato & Iwata, 1993, p. 475). Camarinha-Matos and Afsarmanesh describe a similar concept to the ‘Virtuelle Fabrik’ with the English term ‘virtual enterprise’ (Camarinha-Matos & Afsarmanesh, 1999).

The basic idea behind the ‘Virtuelle Fabrik’ is to think of a network of smaller companies as one large factory with the purpose of dynamically processing orders and producing in small batches while maintaining the autonomy of each participating company (Schuh et al., 1998). This concept can be categorized as a “guided, focal network of enterprises” (Schuh, 2017, p. 266). To establish such a ‘Virtuelle Fabrik’, Schuh *et al.* defined four prerequisites, namely the “cooperation network, principles of cooperation (roles, rules and instruments), marketing of the Virtuelle Fabrik and production in the network” (Schuh et al., 1998, p. 67, own translation). This concept includes six intercorporate services or roles that organize and coordinate the network (Schuh et al., 1998, p. 67), “network coach, broker, performance manager, in- and outsourcing manager, auditor” (Schuh et al., 1998, p. 93, own translation). These roles are not necessarily tied to one person specifically but should be viewed as “tasks that need to be fulfilled depending on the situation” (Schuh et al., 1998, p. 94, own translation). The “broker”, for example, can be an actual person, but the role may be fulfilled by a company in the network as well (Schuh et al., 1998, p. 97 ff.). In the ‘Virtuelle Fabrik’ concept by Schuh *et al.*, in order to create a cross-company value chain, two of the roles need to work together, namely the “broker”, as the one who acquires orders, and the “performance manager”, as the one who puts together the value chain (Schuh et al., 1998, pp. 100–101). Consequently, the knowledge of the performance manager, with regard to the capabilities represented in the network, is essential to the concept’s success. Once the value chain is determined, the companies chosen to produce an order are “activated” (Schuh et al., 1998, p. 31). In a later description of the concept, Schuh details how the cooperation network acts as a “stable platform” that the value creation network, or the actual ‘Virtuelle Fabrik’, is created from to temporarily work together for an order (Schuh, 2017, pp. 270–271).

## 21.3 Discussion

In this discussion, a conclusive line of argumentation is used to answer the three research questions supported by relevant literature.

### 21.3.1 Combined Potential of Local Production and Production Networks

While the organization of production in networks and local production each come with their own advantages, the following section will discuss these together to answer the first question: What is the potential of combining local production and production networks?

To provide a better structure, the various potential benefits will be grouped according to the commonly used three dimensions of sustainability: economic, ecological, and social sustainability (Fischer et al., 2020). Though, some aspects may be relevant to more than one dimension. For the sake of avoiding repetition, they will only be listed in one dimension with a reference to the other affected dimension(s). The goal of this chapter is to give an overview of the most relevant aspects. For further details, literature dealing with local manufacturing and production networks of SMEs should be consulted.

#### 21.3.1.1 From an Economic Viewpoint

As mentioned before, worldwide developments in the past few years have time and again demonstrated how fragile the global value chains that the economy has been relying on really are (Korniyenko et al., 2017). Yet, even before the pandemic and its repercussions, there was an awareness of the need for change, as Larsson stated in his book in 2018:

> Due to impending resource constraints and the need to move towards an increasing share of local production in combination with substantially more resource-efficient models, there will be a need to re-shape entire value chains and a large share of the corporate landscape. (Larsson, 2018, p. 13)

The shortage of medical equipment such as masks, respirators, disinfectant, etc. especially at the beginning of the Covid-19 pandemic very drastically demonstrated the risks of being too dependent on global value chains (Peters et al., 2021, p. 419). Peters *et al.* observed that during this time the local manufacturing of masks surged worldwide, but also that “this took time to implement” (Peters et al., 2021, p. 420).

Larger local networks with more interconnectedness could further provide a multitude of possibilities. The first one is resilience. On the one hand, the shorter the value chains, the less opportunities for interruptions there should be. On the other hand, if one production partner in a network cannot deliver for any reason, e.g., machine breakdowns, too many employees on sick leave, company holiday, too high of a workload, etc., there are others with the same/similar capabilities that could act as substitutes. As a result, delivery times may also be shortened since it is not necessary to wait for one specific company to have the necessary production capacity.

Furthermore, issues regarding a lack of knowledge and resources (Table 21.1) should occur less often since the probability of having someone in the network to make up for that lack gets higher with the network’s growing size. This may enable a wider range of producible goods and more flexibility, thus widening the “narrow product portfolio of SMEs” (Ingaldi & Ulewicz, 2020, p. 15) (Table 21.1), while still allowing them to specialize in their strengths. “Specializing and cooperating as well as building alterable value creation structures” thus allows SMEs to pursue both an effective and dynamic production of goods (Krenz, 2020, p. 279).

#### 21.3.1.2 From an Ecological Viewpoint

Global value chains also mean that goods need to be transported over very long distances via air, water and across land all over the world. The resulting amounts of $CO_2$ emissions are a major contributor to the climate crisis (Vöhringer et al., 2013, p. 295). Shortening these value chains by producing goods locally may contribute to a lowering of $CO_2$ emissions, and thus may aid the efforts to counteract the ongoing climate crisis. Additionally, a closed-loop product life cycle can be facilitated more easily when the product is made close to where it is used and thus where waste is created (Lowe, 2018, p. 48), which could then in turn aid the establishment of a circular economy within cities.

SMEs with a similar product portfolio can also cooperate to consolidate orders, thus utilizing economies of scale and requiring less transport by getting the orders of multiple enterprises delivered at the same time instead of one by one. This may broaden procurement opportunities (KPMG Special Services et al. 2004, p. 20).

It is also conceivable that SMEs could share resources, such as specialized tools, and thus decrease the use of raw materials, while also potentially cutting down on expenses. The coordination of such sharing processes is another example for which the implementation of Industry 4.0 technologies, in this case, e.g., the Internet of Things, could provide significant benefits (Pistorius, 2020, p. 9 ff.).

#### 21.3.1.3 From a Social Viewpoint

Furthermore, it is also possible to get consumers more interested and invested or even involved in the manufacturing of goods when the production takes place in their close vicinity (Lowe, 2018, p. 48). Another factor is that shifting production back to the local economy would also create local jobs and thus potentially bring more prosperity to the region as well as promote the expansion of local infrastructure (Freeman et al., 2016, p. 602; Krenz et al., 2022, pp. 475–476).

Additionally, the more companies of the same or similar trade are in a network, the easier and more affordable it should get to provide educational resources to employees by hosting joint workshops and seminars for trade-specific skills and new technologies/machines (also relevant to economic aspects). This should therefore aid in fulfilling the need for additional qualifications necessary due to I 4.0 technologies (Braun, 2017, p. 19) (Table 21.1).

#### 21.3.1.4 Overview and Critical Reflection

The following Table 21.2 sums up the main benefits that may arise from combining local production and production networks. However, seeing as this is still a relatively new research topic, it makes no claim to being comprehensive.

When considering these expected benefits, it is also important to reflect upon whether or not they would apply to all products currently consumed or used in people's daily lives. Taking the manufacturing sector as an example, it seems questionable if producing bulk goods such as screws and bolts in local production networks would yield the same advantages as, for example, producing highly customizable products such as furniture. This question should be explored further in future research.

**Table 21.2** Overview over the combined potential of local production and production networks

| Economic viewpoint | Ecological viewpoint | Social viewpoint |
|---|---|---|
| Sharing of knowledge, resources, and educational resources | | |
| Increase of procurement opportunities | | Creation of local jobs |
| Increase in resilience | Counteracting the climate crisis | Higher involvement of consumers |
| Shorter delivery times | Utilizing economies of scale | Promotion of local infrastructure |
| Wider range of producible goods | Closed-loop product life cycle | |
| More effective/dynamic production | | |

### 21.3.2 Reasons for the Current Lack of Production Networks of SMEs

Considering the advantages and potential for SMEs of working together in local, highly connected, flexible networks, the question arises as to why such networks have not been widely implemented yet. Thus, the second question from Sect. 21.1 is addressed next: What are barriers for implementing local production networks? Two main reasons are the competitive advantage of large-scale production in global networks as well as the difficulties of implementing local production networks of SMEs.

Global value chains and mass production have some major competitive advantages which is highly likely to be one of the reasons why local production is hard to set up in some cases. Deqiang *et al.* state that "[t]he establishment of the global value chain (GVC) allows firms to minimize production costs across the entire production system" (Deqiang et al., 2021, p. 1). Other financial advantages result, for example, from being able to utilize economies of scale (Matt et al., 2015, p. 186) and outsourcing to countries with the availability of cheaper labor (The Government Office for Science, London, 2013, p. 24). All these monetary benefits allow companies to sell their products for prices that are often significantly lower than the prices of strictly local manufacturers. Despite these factors, recent developments have shown that some advantages may be getting smaller, as demonstrated, e.g., by the reshoring trend, meaning bringing production back from where it was outsourced to (Butollo, 2021, p. 264). There are several reasons for reshoring, one is the development of automation technology that to some degree diminishes the advantage of production in low-wage countries (Butollo, 2021, p. 264). Other reasons include, but are not limited to, the growing importance of co-location, the decreasing wage gap between high- and low-wage countries, and rising transport costs (Bryson et al., 2013, pp. 47–48). In addition, consumers are increasingly asking for more sustainable products (Matt et al., 2015, p. 185), which may also lessen the advantages of global value chains.

Besides the competitive disadvantages of local production, there are also some inherent difficulties when it comes to producing locally in networks. As was mentioned earlier, it seems that SMEs do cooperate with one another, but they often have few, though long-term partnerships (KPMG Special Services et al., 2004, p. 7). In this form of very small networks, the companies are in constant close contact with their partners, whom they have usually built trust with over time (KPMG Special Services et al., 2004, pp. 7, 14). And while these cooperations already provide various advantages, they are limited in size by the time and effort necessary to build and maintain the relationships and trust with the partnering companies (KPMG Special Services et al., 2004, p. 29).

Additionally, even though the concept of the ‘Virtuelle Fabrik’ provides rather detailed information on how a network could operate, it has not been widely adopted or implemented. In fact, there seems to not have been as much research interest in the concept of the ‘Virtuelle Fabrik’, specifically after the early 2000s. Also, Eikebrokk et al. (2021) recently found that SMEs do not really know how to even start such a network.

Schuh und Wegehaupt (2004) reflected upon the reasons for the lack of implementation. They interviewed several enterprises and found “opportunistic thinking of advantages, an insufficient shared infrastructure as well as a lack of a targeted management of the competencies of the partnering enterprises” (Schuh & Wegehaupt, 2004, p. 190, own translation) to be among the listed reasons for the concept not working as expected. Another issue was putting too much emphasis on trust as the basis for the network, as this led to the opposite: a “culture of mistrust” (Schuh & Wegehaupt, 2004, p. 190, own translation). From the customers’ perspective, the services and/or products appear to be too unclear or too broad, leading to mistrust in the network’s abilities (Schuh & Wegehaupt, 2004, p. 190).

One of the biggest issues, however, is the governance of the network. Schuh and Wegehaupt found that while “the centralized leadership by a dominant enterprise is rejected” (Schuh & Wegehaupt, 2004, p. 190, own translation), there is still a need for “clearly defined responsibilities and contact partners” (Schuh & Wegehaupt, 2004, p. 190, own translation). In short, the idea of complete decentralization and an absence of hierarchy did not work the way it was originally envisioned (Schuh & Wegehaupt, 2004). Instead, Schuh and Wegehaupt suggest a concept using a “focal management entity” (p. 191 ff.). They assign four tasks to this new entity: „Building the cooperation network”, “Active and passive marketing”, “Preparation and negotiation of contracts [and] Project management” (Schuh & Wegehaupt, 2004, p. 195, own translation). There is however no further elaboration on how this “focal management entity” would be established.

To the authors’ knowledge, the Observatory of European SMEs or as it is called now, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (GROW), has also not published another report with updates on its findings since 2004.

In conclusion, it seems that not much has changed in the way SMEs cooperate since the first efforts to revolutionize production networks of SMEs in the 1990s, despite new opportunities opening up through technological advances and Industry 4.0.

### 21.3.3 Facilitating the Implementation of Local Production Networks of SMEs

After highlighting the potential of local production networks of SMEs and taking a closer look at the reasons for them not being a common occurrence yet, as well as discussing why local production might be gaining in relevance compared to global production, it appears important to conduct further research in this field. Therefore, the third question needs to be addressed: What are the conditions and prerequisites to facilitate the successful creation of local production networks?

From Sect. 21.3.2 several prerequisites for the facilitation of a viable, successful network of local SMEs can be derived, as shown in Fig. 21.1 and explained in more detail below.

The initiation of a network requires a significant amount of effort and investment without warranting success. Therefore, an initial "push" is necessary to initiate a network, and Eikebrokk *et al.* believe this to be "more realistically stimulated and facilitated by an external party, such as academia or an industry association" (Eikebrokk et al., 2021, p. 363).

There should not be a hierarchy, though some kind of "focal management entity" is still necessary (Schuh & Wegehaupt, 2004, p. 191 ff.). Schuh and Wegehaupt found in their reflection on the 'Virtuelle Fabrik' that enterprises did not want to be restricted by a hierarchy, but actors in the network that did take on coordination responsibilities were not necessarily the most suitable for the role in terms of competency either (Schuh & Wegehaupt, 2004, p. 192). Therefore, the network should also not simply rely on any single person or any enterprise to step up to do managerial tasks.

There should be no need for constant communication among the network partners. The large amount of effort necessary to cultivate cooperation through frequent and direct communication is the main reason why SMEs have only been able to maintain a limited number of partners so far (KPMG Special Services et al., 2004, p. 29 ff.). For the same reason, trust among the network enterprises cannot rely solely on close personal relationships as these take up too much effort to build in a larger network. On the flipside, trust also cannot be the sole basis for the partnerships, since Schuh und Wegehaupt (2004) found that this can lead to the opposite effect, i.e., mistrust.

There should be no need to share specialized knowledge between the network partners verbally or in writing, instead, knowledge should be transferred via the product itself (Krenz, 2020). This means that only the "interface between the components is to be configured" (Krenz, 2020, p. 289, own translation), i.e., only the point at which the product is handed over to the next network partner.

This list should be understood as a baseline for efforts towards the creation of local production networks of SMEs. It does not hold a claim to completeness. The better the reasons for the current lack of these types of networks are understood, the more stipulations can likely be added.

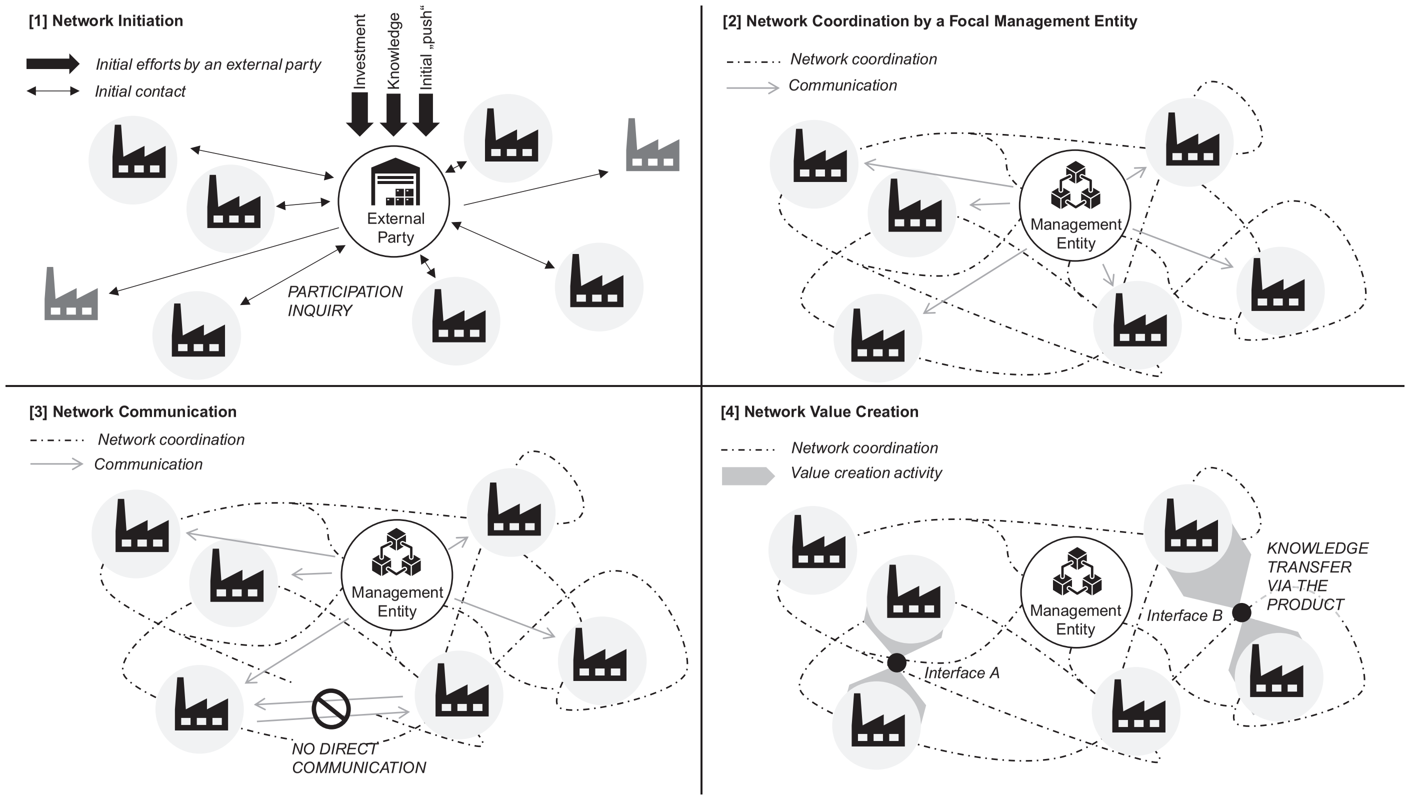


**Fig. 21.1** Prerequisites for the facilitation of a viable, successful network of local SMEs

Furthermore, the points elaborated above can only provide a framework for the initiation of a successful local network of SMEs. In order to find concrete recommendations for action and solutions, more research – both conceptual and empirical – is necessary.

## 21.4 Summary and Outlook

The goal of this paper was to discuss what role local production networks of SMEs could play in the future of producing locally.

It was found that on the one hand, there is vast potential in this type of production – especially in the combination of the advantages of producing locally and of producing in networks – known for years, such as the sharing of knowledge and resources within the network. On the other hand, efforts to actually bring them to fruition have rarely been successful as of yet. While there has been some research interest in the reasons for the lack of success of SME network concepts, more empirical research could provide further insights and enable (more) modifications and improvements to existing concepts.

It also seems that the possibilities of modern information technologies, that have made great strides in the past decades, have not been fully applied to the context of local production networks of SMEs yet. In fact, as shown in Sect. 21.2.1, there is still much to be done in terms of introducing and implementing Industry 4.0 technologies to SMEs. This is especially interesting because of the reciprocity of networking and Industry 4.0, meaning the implementation of I 4.0 technologies can enable and enhance collaboration activities in production networks, and vice versa.

Lastly, a list of stipulations to facilitate the implementation of local production networks of SMEs was derived. This list is created as a baseline that should be expanded on in the future through further conceptual and empirical research.

In conclusion, local production in networks of SMEs holds a lot of untapped potential, such as the support of a circular economy and Fab Cities with smaller value creation cycles. Future research efforts should focus on accessing these in order to contribute to the shift back towards the local production of goods.

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