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What Are The Role And Capabilities Of Fab Labs As A Contribution To A Resilient City? Insights From The Fab City Hamburg

Lennart Hildebrandt[1], Svenja Zadow[1], Luisa Lange[1], Michel Langhammer[1], Manuel Moritz[1], Tobias Redlich[1], Jens P. Wulfsberg[1]

[1] Helmut-Schmidt-University / University of the Federal Armed Forces Hamburg

Abstract

Recent events such as the COVID-19 pandemic or the Ever-Given accident in the Suez Canal, which have led to local product shortages and negative social and environmental impacts, highlight the need to build resilience in areas that are highly affected by such events: in cities. One aspect of a multidisciplinary concept of resilient cities is the local manufacturing of physical products, which currently is mainly based on globally complex supply chains. The resilience of a city can be impaired if the supply of consumer goods can no longer be guaranteed, e.g., due to the fragility of supply chains. From this perspective, one of several pathways to a more resilient city is the emerging movement of open production sites (so called Fab Labs), where physical products can be produced or repaired in a distributed way by the consumers themselves. In metropolitan areas such as Hamburg, Fab Labs form networks including makerspaces, open workshops and educational institutions – so called Fab Cities. This article highlights the role of Fab Labs with regards to urban resilience and displays the capability of the Fab City Hamburg to contribute to the resilience of the city. To explore these capabilities in a pilot study, semi-structured interviews were conducted with makers and operators, and different Fab Labs were explored via participant observation. This article demonstrates that Fab Labs can contribute to a resilient city - especially from the perspective of manufacturing capability but also regarding the development of technical education. However, there are clear limitations with regards to the vertical range and manufacturing diversity.

Keywords

Resilient City; Urban Production; Production Sovereignty; Fab Lab; Fab City

1. Introduction

The COVID-19 pandemic has affected people around the world and, in some cases, drastically changed local living conditions. Contact restrictions and other limitations have been introduced to contain the spread of the virus. This has had a major impact on cities and their inhabitants, where, in many places, public life has been reduced to an absolute minimum and normal life was disrupted.

Despite these measures, very high numbers of COVID-19 cases occurred locally, leading to supply shortages of consumer goods, personal protective equipment and other devices (e.g., lung ventilators) especially early in the pandemic [1]. In the case of personal protective equipment one reason was that countries (specially in Asia) which manufacture personal protective equipment needed the equipment for their own needs at the start of the pandemic (e.g., China manufactures four-fifths of the world's protective clothing) [2,3]. However,

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it also became apparent that manufacturers outside the Asian region did not have the needed capacity and/or infrastructure to respond adequately to this high and short-term demand [4].

A similar lack of resilience through our global supply chains has occurred in the Ever-Given accident in the Suez Canal in March 2021, which had blocked the canal for six days. The problem was not so much the breakdown caused by the individual ship, but the six-day closure of one of the world's most important shipping channels. In total, 422 ships jammed and failed to reach their destination on time, causing delivery delays and damage to industry, wholesale and retail. This resulted in an estimated loss of supply of around 9 billion euros per day [5,6].

In both cases, entire countries were caught more or less unprepared due to the short lead time and immense and continuous demand for equipment. These problems manifest themselves especially where large crowds gather. In cities, there is a lot of contact with people in public spaces, a continuous and high demand for physical products, and at the same time, usually little manufacturing activity in the center. On the other hand, there are also large supply chains, but as the examples of COVID-19 and the Suez Canal show, they can be vulnerable to external impacts. These problems and resulting impacts on cities could even intensify in the future, as forecasts indicate that 70% of the global population will live in cities by 2050 [7].

For this reason, governments, scientists, urban planners and other actors have been coming up with concepts to make cities more independent (e.g. from global trade networks) and resistant to external influences (e.g. climate influences). The main contents of such concepts, which can be summarized under the term urban resilience, include new regional cooperations, new neighborhood developments and promoting civil society engagement and co-production.

Such approaches also exist in the Hamburg metropolitan region, where physical products have already been developed and manufactured by citizens. This approach, which is practiced in Hamburg and other cities globally, is called Fab City. In this paper, we present insights from the Fab City Hamburg and show what contribution Fab Labs can make to increase a city's resilience in terms of production, innovation and education in order to be less dependent on external influencing factors.

2. Theoretical Background

2.1 Resilience and Resilient Cities

The concept of resilience is not a new notion and has its roots in the Latin word "resilire", which describes the ability of an entity or system to elastically restore its form and position after a disturbance or disruption. But as clear as its origins seem, as ambiguous seems its current definition. The polysemous concept of resilience varies in its meaning depending on the discipline, whereas this work focuses on urban resilience or resilient cities. The literature on this is numerous and has grown rapidly, especially in the last few years, with just about 40% of the total publications with the keyword "urban resilience" emerging in 2020 and 2021 [7]. For a detailed look at the definitions, see Merrow 2016 [8].

In their review of smart solutions and technologies during the pandemic, Sharifi et al. use the definition of the National Academies of Sciences, Engineering, and Medicine as a basis, as it combines different approaches and disciplines. According to this, resilience is defined as the capability to prepare and plan for, absorb, recover from, and more successfully adapt to actual or potential adverse events [9,7]. Sharifi et al. note that resilience is an approach to the management of socio-ecological systems that aims to develop an integrated framework to bring together the (often) fragmented, diverse research on disaster risk management [7]. In their review, Masnavi et al. [10] studied the exploration of the concept of urban resilience for use in urban planning and focused in detail at the conceptualization of a resilient city. As they explain, a common aspect of many approaches is the ability to withstand, resist and respond positively to pressure or change.

In addition, Patel et al. concluded, that resilience is not only about restoring functionality, but also about correcting existing social, political and economic structures that may have increased vulnerability and limited the ability to cope with the crisis [11]. It is also essential to note that resilience is not a rigid concept, but a dynamic set of conditions and processes [12].

The German Institute for Standardization has also published an ISO standard entitled "Sustainable cities and communities - Indicators for resilient cities" [13], which describes the concept of a resilient city in detail. Thus, by maintaining and restoring essential basic structures and services in a sustainable manner and through risk management practices, a resilient city is able to withstand, absorb, manage, adapt, transform and recover from the impacts of shocks and stresses [13].

In the meantime, numerous policy papers and reportings have been published, providing practical guidelines for making a city or region more resilient. Examples of this include the memorandum "Urban Resilience - Ways to create Robust, Adaptive and Viable Cities" of the German Federal Ministry of the Interior, for Building and the Home Affairs (BMI), which serves as a guideline for contemporary urban policy in Germany and Europe. It contains ten recommendations for action to increase a city's resilience, e.g., promoting civil society engagement and co-production or utilizing the potential of the neighborhood level [14]. Another example is the vision of the German Federal Environment Agency for a "City for Tomorrow", in which, for example, higher resource protection and more space for encounters are addressed [15].

A commonly shared aspect, when defining the term urban resilience or resilient city is an emphasis on the human factor and the contribution of human centered systems towards a city's resilience, i.e. its ability and performance to anticipate, prepare, react, adapt and recover [16,17,12]. Based on these findings, the following working definitions of key terms of urban resilience is used for this paper:

- Anticipate - A city has the ability to foresee external changes.
- Prepare - A city has the ability to prepare for upcoming changes of external influences.
- React - A city has the ability to react at short notice to changes of external influences.
- Adapt - A city has the ability to adapt to changes of external influences in the long term.
- Recover - A city has the ability to recover from negative external influences.

2.2 Maker Movement, Fab City and Fab Labs

One approach to increase a city's resilience can be fostering technological literacy in conjunction with the creation of easy access production opportunities. This idea is part of the so-called Maker movement, originating from the USA, which focusses on self-production or community-based production of goods by prosumers (production by consumers) [18]. This new way of value creation offers potential in the areas of education, innovation and production [19]. In this movement, education (especially technical literacy) is fostered by an experimental learning environment, including rapid-prototyping methods of new product designs. In open-source communities, socio-technical contexts can be understood and evaluated and knowledge can be shared and accessed. This is a creative basis for innovation, as one's own problems can be better translated into technical and novel solutions through newly gained and existing knowledge. With this bottom-up approach, individual open source physical products (so called Open source hardware) can be developed and manufactured by their future users. "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" [20–22]. While the Maker Movement is more about fun, fabrication and community, essential content has been incorporated into the Fab City approach [23,24].

In the Fab City approach, founded in 2014, production is brought back to the city and carried out in the local neighborhood [25]. The goals of this city network (there are already 38 official Fab Cities distributed around the world) include greater independence from complicated transport logistics, sharing open (production) data in the network, building up or recovering technological literacy and developing new technologies at the point of need. The actual production in the neighborhood takes place in open production sites, so-called Fab Labs, with the help of easy-to-use digital production machines (e.g., 3D printers, CNC mills, laser cutters) [26]. Fab Labs are places where people can work creatively, innovate and produce physical products [27]. They provide access to production infrastructure for the local population through their equipment of hand tools and digital production machines. Besides individual products, small batches can also be produced, as exemplarily demonstrated by the production of face shields and masks during the COVID-19 pandemic outbreak in many places [28,29]. The term Fab Lab was first initiated at the Massachusetts Institute of Technology in 2002, and since then the number of such places has been growing rapidly: according to the Fab Foundation, a US non-profit organization for supporting the international Fab Lab network, there are already over 2000 such places worldwide.

Fab Cities with Fab Labs should be clearly differentiated from other innovative production approaches, which focus on raising the competitiveness on the market, such as frugal production or reconfigurable production systems [30,31]. The core strength of Fab Cities with Fab Labs is the triad of education, innovation and production as a whole. Fab Cities are more than innovative production approaches. Fab City "is about radical transformation, it is about rethinking and changing our relationship with the material world, in order to continue to flourish on this planet" [25].

Fab Labs and Fab Cities already provide an infrastructure that allows local innovation, urban production and knowledge building by everyone. However, full resilience of a city is clearly beyond the capabilities of a Fab Lab or current Fab Cities. But the need for a (more) resilient city is becoming increasingly clear. Therefore, the question arises: What contribution in terms of education, innovation and production can Fab Labs in Fab Cities make to achieve resilience in a city? In this paper, we present insights and results on the analysis of capabilities of the Fab City Hamburg based on selected Fab Labs.

3. Methodology

A qualitative and exploratory research approach with mixed-methods using data triangulation of semi-structured interviews and participant observation has been chosen for answering the research question. This approach was chosen since no data on this topic in cities is available in literature, therefore data was empirically collected as part of this study. According to R. K. Yin [32], a single context has been chosen. This is justified by the unique situation of the COVID-19 pandemic in combination with the Fab City approach, which is still not widespread, allowing data to be collected in a state that was previously inaccessible to scientists.

To explore the contribution of Fab Labs to increasing resilience, Hamburg was chosen as the research subject. Hamburg is home to more than 15 Fab Labs and other open production sites. Since 2019 the city has officially been part of the Fab City network. In the Fab City Hamburg, five universities and research institutions, three different authorities and various employees and volunteers are busy building a physical and digital infrastructure to be able to produce in the urban space of the city. Combined with the single context and the study of a single phenomenon (contribution of Fab Labs to increasing resilience) with multiple embedded and independent units of analysis (Fab Labs in Hamburg), this is an embedded single-case design.

Data was collected qualitatively in July 2021 by means of semi-structured interviews in nine Fab Labs with a total of 18 participants. For this purpose, an interview guideline was created with different questions that have an influence on resilience in the areas of education, production and innovation. These include internal lab processes, internal and external knowledge management, flexibility and speed of decision-making paths, demand messages, cooperation and collaborations, as well as production processes and planning and control systems in the respective Fab Labs.

The interviews were recorded in audio, anonymized, transcribed and evaluated and compared using qualitative content analysis according to P. A. E. Mayring [33]. This type of methodology was chosen in order to provide comparability between statements and information on the same topics through the semi-structured nature. At the same time, the semi-structured nature offers a great deal of freedom for interviewees to comment in greater depth on a subject, allowing the interviewer to gain new insights and internal knowledge.

One lab manager and one maker were interviewed per Lab. The group of people was intentionally limited and selected this way because we want to explore the influences on resilience and related events on site in a Fab Lab (shopfloor). The nine Fab Labs fall into three main categories: government/university Fab Labs, community-driven Fab Labs, and corporate Fab Labs. On the one hand this division was made to obtain the different views of a Maker or Lab manager for an individual Fab Lab. On the other hand, the categorization of the Fab Labs is necessary because significant factors with regards to people, technology and organization (e.g. financing, personnel, users, equipment, organizational structure and process organization, aim) differ significantly (for overview see figure 1). Since Fab City Hamburg continues to be in the making and only a few actors from the Maker Movement have contributed to this area so far, the interview partners from the three categories were chosen partly (2 Fab Labs) from the Fab City Hamburg environment, but mostly (7 Fab Labs) independently. However, the core statements of the interviews contained the same content, and a theoretical saturation was recognizable.

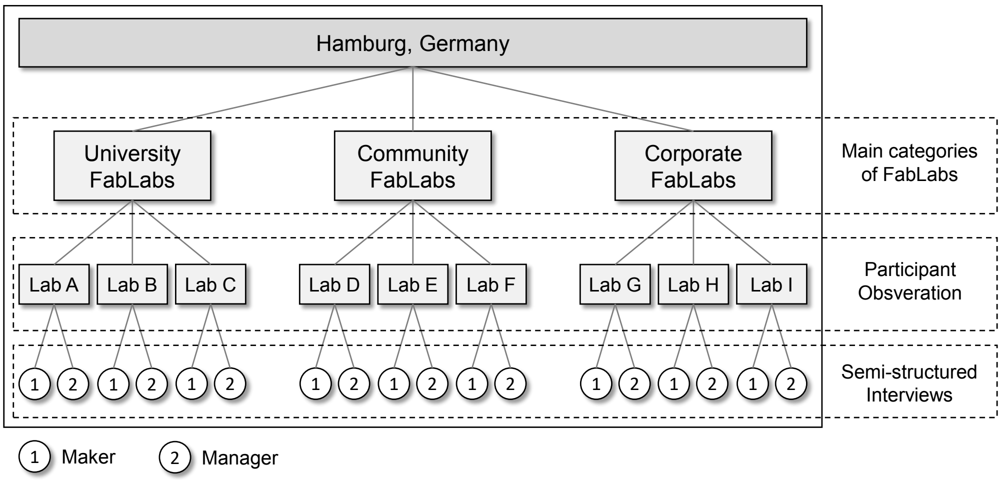

Figure 1: Research object

Additionally, as the second method of our mixed-methods approach, each Fab Lab was observed in a participatory (purely physical presence) and open manner. This observation was also conducted in a semi-structured manner using semi-structured observation guides to ensure comparability but also the possibility of deeper insights. The main focus of the observation was on the machines on site, which allowed to draw conclusions about the actual production capability. The results were systematized for the individual Fab Labs and the three main categories and documented in sub- and main tables. The evaluation was also carried out using qualitative content analysis. The mixed-methods approach combined with data triangulation and the large number of different Fab Labs and interview partners (in Hamburg) was chosen to best reduce potential bias.

4. Analysis and Results

In the following analysis, the findings and insights from the interviews and participant observation are used to evaluate the contribution of Fab Labs in the areas of innovation, production, and education promoting urban resilience. We see innovation, production and education as part of the solution to respond to the five identified fields of resilience. For this purpose, the definition derived in section 2.1 for building a resilient city, including the five sequences anticipation, preparation, reaction, adaption and recovering, is used to examine the contribution Fab Labs offer to building a resilient city in the dimensions of education, innovation and production (see figure 2). The processes behind each dimension are not considered as they are very individually dependent on the implementation of these dimensions by the actors. By deriving the dimensions through the already existing processes which were observed show the effectiveness and feasibility of the processes.

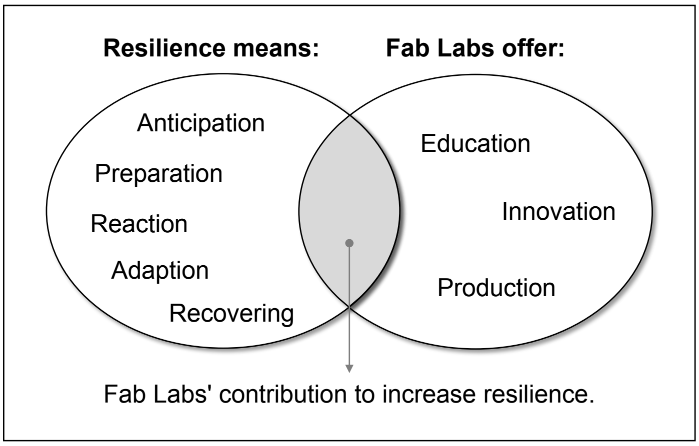

Figure 2: Intersection between resilience and Fab Labs

4.1 Education support

As the interviews show, the preparation of upcoming disturbances is supported by the Hamburg Fab Labs offering production spaces which are openly accessible, as well as offering openly organized workshops to transfer knowledge on how to use these spaces in terms of configuration of available machines and usage of computer aided design and development tools. These workshops reach from build workshops all the way to soldering, sewing and laser-cutting workshops. They take place at the labs directly and are organized for members of the local community as well as externals.

During the COVID-19 pandemic, it became clear that these workshops are essential to the use of Fab Labs, as they can uniformly bring a group of interested parties of six to twelve people to the point of being able to independently operate a machine as well as the associated software. For 3D printers, such a workshop lasts between two and four hours and can already be conducted with teenagers. Through these workshops as a preparatory measure, it was consequently possible to put people in a position to subsequently help as a workforce. In addition, participants then have the skills to use the site to develop and try out technical solutions, building further knowledge independently.

In addition to such workshops on the simple use of machines, there are also build workshops that are conducted throughout the community and usually rely on the use of open source hardware. The conducted build workshops represent the process of local replication of open source hardware designs. This openness enables a deeper insight into the technical fundamentals of the hardware as such and provides opportunities of re-designing as well as repairing the hardware. The workshop offers are mostly bundled and available on one particular day of the week (so-called open lab day). Through these open offers and the collaborative organization of these workshops by the community and managers, knowledge is passed on to the civilians, technical literacy is built up and promoted, and the resilience of a city is fostered through the possibility of self-production of consumer products and machines.

Interviews with the lab managers, particularly in community-driven fab labs, have shown that the lack of professional staff to organize and conduct these workshops and the financing of the activities are the most common issues hereby. This problem is much less prevalent in corporate Fab Labs, where personnel capacities for workshops are more limited (due to lack of time). Another problem is the low level of cooperation between the Fab Labs. There is no Fab Lab in Hamburg that has a strategic cooperation with other Fab Labs, which means that resources (including resources for workshops) can only be used inefficiently.

"Unfortunately, there is no real cooperation. It's just a bit, when we are overloaded, I send our students somewhere else to print. But cooperations unfortunately not." - University Fab Lab manager

The constant documentation of this knowledge is essential for the use of open knowledge and the (machines building) workshops already described. Accompanied by the offer of open educational resources provided by Fab Labs in Hamburg, the knowledge is thus digitally available and regardless of location. Lessons learned throughout shock periods are accumulated in the described open-ended manner and can be used for new learning cycles. Thus, the skills learned are retained and provide a long-term basis for responding to new events. Such concepts are essential to form an educational basis to build up preparational and recoverable resilient structures in cities. As the interviews have shown, the documentation of this knowledge is still a widespread problem, since the existing knowledge is insufficiently processed and summarized for posterity, which currently still leads to difficult learning conditions.

4.2 Innovation support

Fab Labs offer a significant contribution to fostering innovation, through their open workshop, whereby users have the opportunity to develop technical solutions to problems and produce prototypes. This gives rise to new products that can subsequently be used in the local area. Users are supported in their innovations by innovation consultants or by the lab managers, who are available to answer questions about machines and technical solutions during the respective opening hours (open lab days). However, it is also apparent that insufficient funding and a lack of knowledge mean that the potential of this advice cannot yet be fully exploited.

Fab labs in conjunction with open source hardware offer great potential for innovation, as the designs of these products are available digitally and may be adapted by any user. The knowledge of a larger community lead to quick design adjustments and improved products. Fab Labs also offer a way to quickly develop and try out new prototypes (similar to the lean startup approach of "build, measure, learn"). According to the interviews, in Hamburg this knowledge and opportunity was massively used during the COVID-19 pandemic, when Face Shields and Face Masks based on an open source hardware design were developed, refined, and produced in several Fab Labs (especially base-funded university Fab Labs). This rapid reaction enabled the products to be adapted to local (especially climatic and regulatory) constraints and subsequently, in conjunction with the manufacturing infrastructure, to supply several hospitals in Hamburg, Schleswig-Holstein and Madrid. [28,29]

"A colleague then presented the first adapted concepts for the face shield, for example. Then we went into the first prototype phase, where we tried to see what could be printed and how, and how the whole process could be optimized. Then again a bit of try and error. First attempts at how we can stack things for maximum effectiveness. And then it worked." - University Fab Lab user

The innovation potential described above can also be found in the area of adaptation and recovering, where technical solutions can be (further) developed to meet local needs. An example from an interview with a manager of a university Fab Lab shows the potential of local communities in idea competitions, where the citizens are invited to contribute to specific topics where new innovative solutions are needed, or existing solutions are optimized or redesigned based on local gathered requirements.

This community-based innovation process operated and curated in Fab Labs supports the city's ability to prepare for upcoming events by designing new technical solutions, to react to events by deploying the solutions in a rapid way and to adapt flexible to new states of urban settings. In doing so, the open innovation cycle is iterative and always adapts to new circumstances, which can also go beyond a state of shock.

4.3 Production support

The creation of a responsive and adaptable city infrastructure is supported by Fab Labs through the provision of small open physical production facilities and machines. This production infrastructure provides a lever for action to produce needed products locally and as far as possible without dependencies in the global supply chain. This allows us to build and maintain a production sovereignty that enables us to manufacture physical (simple) everyday objects. The big advantage here is the low variance of the raw materials: for example, the single raw material (filament) of the 3D printer can be used to produce a very wide variety of products.

The machines in a Fab Lab vary but are mostly standardized. The most important machines as well as the materials to be machined, typical machining times and typical usage of the machines (based on the interviews) are shown in table 1. Fab Labs cover a large scale of plastic processing tools (especially through the use of 3D printers). In addition, metal and wood are other materials that can be processed locally. However, the interviews show that there are limitations in the processing complexity. The given degrees of freedom in processing are typically limited to 3 axes (x, y, z direction) in the examined machines (for example 3-axis CNC milling machines). In terms of the value of the machines, it has been shown that university and corporate Fab Labs tend to have more financial resources to purchase higher quality and multiple machines related to a manufacturing process. In community-driven Fab Labs, on the other hand, there are many cheaper machines or self-built solutions (as open source hardware) that are, however, very well adapted and appropriate to their area of application.

Table 1: Machines in Fab Labs

Digital machines	Materials	Processing time	Dissemination	Usage
3D printers	Plastics (especially PLA, TPU, ABS)	Hours to days	Very high	High
Laser cutters	Especially wood, plastics, metal	Minutes	High	Very high (most used machine)
CNC mills and lathes	Wood, plastics, partly metal	Minutes, partly hours	Medium	Medium
Vinyl cutters	Vinyl, paper	Minutes	Low	Low
Circuit board printer	Circuit boards	Minutes	Low	Medium
3D scanners	Any	Minutes	Low	Medium

Due to these restrictions, there are clear limitations with regards to the vertical range of manufacture, which is additionally restricted by the quality of the machining. However, these machines are perfectly adequate for the production of physical products where lower quality requirements are placed on the machining and/or only simpler geometries are used. As a current example, the production of officially approved face shields in larger quantities (up to 5,000 face shields per week) with 3D printers and laser cutters in a single Fab Lab should be mentioned [28,29]. In addition to the manufacturing of physical products, the existing machines and tools can also be used for the maintenance and repair of goods which support the city's resilience recovery process.

With regard to the possible output of a Hamburg Fab Lab network (i.e. Fab City Hamburg) and the ability to react to external influences, the potential of a distributed and networked production infrastructure with Fab Labs was also analyzed. The interview results show that Fab Labs as locations see themselves as independent organizations with mostly no manufacturing organization.

"There is almost no production organization structure at all. [...] For example, someone in his telegram group throws something into the room about what needs to be done or an idea about what we can do, and then we talk about it. This is then organized somehow." - Community Fab Lab manager

Fab Lab managers and Makers are also primarily focused on a single Lab. This leads to manufacturing that is currently not very efficient, since, as the interviews show, machine capacities are unnecessarily kept on hand and/or not used. However, the individual Fab Labs cooperate regionally with actors such as universities, schools, SMEs or associations in a cooperation network, but as shown not in a production network.

In addition to the physical infrastructure, some of the Hamburg Fab Labs (especially university and community driven Fab Labs) host and use open-source software tools for design and development of open-source hardware (e.g., image processing programs or CAD/CAM software) or for operating their organization (e.g., open source cloud software and development platforms with built-in version control). Through this use, Fab Labs can offer digital infrastructure for production systems which stays digital sovereign and flexible used by community members and external partners to create and exchange knowledge. In terms of the five resilience sequences, this offers advantages particularly in preparation, reaction and adaptation, since the software infrastructure cannot be easily deactivated from the outside, e.g. in a defense case. It also ensures that the knowledge (e.g. designs, production data) stored on the local servers and in the local software applications is available for the long term. The interviews showed that such a data structure is currently under development, especially in the university and community-driven Fab Labs.

Besides the production capability, the factor of decision-making process in Fab Labs is important for the flexible reaction and adaptation in a resilient city. This process depends on the legal and organizational structure. The observed community driven Fab Labs in Hamburg are operated as associations. Decisions are made by consensus at the board or member level. For larger and strategic decisions, there is usually a two- to four week lead time to vote on issues that need to be decided. This circumstance is an obstacle to flexibility, though it is a very democratic process. In commercial and university driven labs, decisions are made by the responsible lab managers or delegated to corresponding employees. The consistently small-scale organizational structures of these Fab Labs enable fast and flexible decision-making, which contributes to an optimized implementation process when needed (see face shield and face mask production during the COVID-19 pandemic in [28,29]. In general the effort of processes is very dependent on the organizational structure of the actors.

After providing an overview of Fab Labs' contributions to resilience enhancement, the following section discusses key findings and identifies limitations. On this basis, the authors recommend a research agenda for future in-depth investigations

5. Discussion and Research Agenda

The aim of this paper was to elaborate in a pilot-study the role and capabilities of Hamburg Fab Labs as a contribution to making Hamburg a resilient city. As displayed in the analysis, the production capacity and product variety of the Hamburg Fab Labs is still very limited. Currently, only the processing of simple geometric products and/or products with lower quality and quantity requirements is possible. Furthermore, especially the community driven labs are currently facing the major issue of personnel shortage. This is partially due to the difficulty of funding, which is why the work is largely based on volunteer labor. University and corporate driven labs do not/less have the problem.

Even though their potential is currently greatly reduced e.g., by a lack of cooperation among the individual labs, especially the regional cooperations deriving from singular Fab Labs can still have a larger impact on strengthening a city as such [34]. As seen in the analysis, the Fab Labs in Hamburg have several ways of contributing towards the resilience of the city of Hamburg. Through their flexible adaptation and quick reaction, they play a significant role when it comes to Hamburg's ability and performance to prepare, react, adapt and recover. Anticipating structures, however, are not covered by Fab Labs as they do not have capabilities of foreseeing external disturbing events or shocks. Especially within the area of material processing, Fabs Labs in general prove as great support with regards towards a city's resilience. Additionally, the innovational and educational contribution of the Fab Labs are important factors when it comes to strengthening urban resilience.

It must be kept in mind that resilience is a concept which is rather abstract. There can never be "the resilient city" [35] and furthermore, a city will never become resilient by the mere existence of Fab Labs and the Maker Movement. Nevertheless, it can be noted that Fab Labs in general can contribute to strengthening a city's resilience to certain events, such as shortages of certain products or natural disasters, by keeping a production infrastructure in the neighborhood, by sharing knowledge, and as places of rapid and adaptive innovation. As general key potentials of Fab Labs are the areas of education, innovation and production [19], the main findings (both advantages and disadvantages) of this study can be applied to other Fab Labs as well. However, since this study only refers to selected Labs in the Hamburg area, it is recommended to take a closer look at other facilities. A comparative study that includes additional German and European cities would underpin this concept. A focus can be placed on comparing regions with and without a Fab Lab network or a strong Maker movement.

However, this pilot study is also just the start of data collection. To more deeply understand the Fab Labs' contribution and potential, we specifically propose the following research agenda, first for the Hamburg area (for deeper understanding), and subsequently in further national and international (Fab) cities with a wider range of interview partners (both in terms of number and in terms of orientation, e.g. adding municipal partners or corporate partners):

1. **Product Design & Production**:
   How can easier-to-use and more digitized (open source) machines enable Fab Labs to achieve a greater design complexity, greater production depth, and greater output?
   Which effect has an improved strategic collaboration and networked production planning and control systems on the output of Fab Labs?
2. **Education and interactions**:
   How do Fab Labs influence local neighborhoods and the technological literacy of users?
   What further potential do Fab Labs bring within these areas?
3. **Finance**:
   Which new funding models for staff, particularly in community Fab Labs, that support on-the-ground work, are suggested?
   Which further limitations within the labs' volunteer work occur?
   Which types of financing models are recommended for Fab Labs, allowing short-term and flexible use without membership or other obligations?
4. **Further sectors**:
   Which influence do Fab Labs have on further fundamental sectors such as healthcare, waste management or food?

6. Conclusion

This paper evaluates and reflects on the role and capability of Fab Labs in the Fab City Hamburg as a contribution to a resilient city. In order to investigate this concept in a pilot study, semi-structured interviews and participant observations have been conducted in nine different Fab Labs within city. The results of these interviews and observations have been compared with the current state of research towards creating a resilient city. For this purpose, a working definition of a city's resilience, including the ability and performance to anticipate, prepare, react, adapt and recover, was defined and cross-referenced with the current contributions of local Fab Labs in the areas of education, innovation, and manufacturing. The data and results presented in this paper suggest that Fab Labs can have a strong contribution towards a city's resilience. In particular, the ability to build technical knowledge locally in the neighborhood, to develop technical innovations alone or in groups, and to subsequently manufacture prototypes or physical products are main drivers towards forming a resilient city, which are strengthened and enhanced throughout Fab Labs. These drivers form the core of the Fab Labs` contribution to support cities in their approach to resilience. However, this study also highlights the limitations of Fab Labs for example in the manufacturing context with regards to manufacturing depth and diversity. Future work within this area should include studies focusing on other (inter-)national cities with a wider range of interview partners and different stakeholders. Essential will be further research on production machines and networks, funding for human resources and Fab labs, and influences on education and neighborhoods to more deeply understand the contribution of Fab Labs to urban resilience.

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9. Biography

Lennart Hildebrandt (*1994), M.Sc. studied mechanical engineering (product development and logistics) at Helmut-Schmidt-University in Hamburg and joined the Institute of Production Engineering (LaFT) in the Department of Mechanical Engineering there in 2019. His research focus is on value creation systematics and urban production in connection with Fab City and open source hardware.

Svenja Zadow (*1990), M.Sc. studied agricultural economics at Kiel University (CAU) and joined the Institute of Production Engineering (LaFT) in the Department of Mechanical Engineering at Helmut-Schmidt-University in 2021. Her research focuses on value creation systematics, sustainable consumption, urban food production and occurs in the context of Fab City.

Luisa Lange (*1993), M.Sc. studied mechanical Engineering at UAS Constance and Jönköping University in Sweden. She joined the Institute of Production Engineering (LaFT) in the Department of Mechanical Engineering at Helmut-Schmidt-University in 2021. Her research focuses on value creation systematics and the human factors engineering in new connection with Fab City and open source hardware.

Michel Langhammer (*1990), M.Sc. studied electrical engineering (automation systems) at Baden-Wuerttemberg Cooperative State University (DHBW) Stuttgart and Hamburg University of Applied Sciences (HAW). He joined the Institute of Production Engineering (LaFT) in the Department of Mechanical Engineering at Helmut-Schmidt-University in 2021. His research focuses on open source hardware, sustainable manufacturing and open educational resources.

Dipl-Ing. Manuel Moritz (*1985), MBA studied mechanical engineering at Helmut-Schmidt-University in Hamburg and joined the Institute of Production Engineering (LaFT) in the Department of Mechanical Engineering there in 2015. His research focus is on value creation systematics in connection with Fab City and open source hardware.

Dr.-Ing. Dipl.-Wirt.-Ing. Tobias Redlich (*1981), MBA is the senior engineer at the Institute of Production Engineering (LaFT) in the Department of Mechanical Engineering at Helmut-Schmidt-University in Hamburg since 2013. His research focuses on value creation systematics and the impact of new value creation patterns on production engineering and production management.

Univ.-Prof. Dr.-Ing. Jens Wulfsberg (*1959) is head of Chair of Production Engineering in the Department of Mechanical Engineering at Helmut-Schmidt-University in Hamburg since 2001. The main research areas at the Manufacturing Technology Laboratory (LaFT) are value creation systems, robotics, micro manufacturing as well as additive manufacturing and lightweight construction.