EX MACHINA

A Campus for Timber Industry 4.0

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COMPLEX PROJECTS
Bodies and Building Berlin
AR3CP100

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Bodies and Building Berlin
Digitalization

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INTRODUCTION

01

1.1 Thesis Topic

Industry 4.0, also known as the fourth industrial revolution, has been a hot topic ever since it was proposed back in the 2010s[1]. In essence, it is a production mode reliant on the implementation of various technologies facilitating the collection, sharing, and real-time processing of data. It bridges the gap between cyberspace and the physical environment to enable innovative digital production systems[2]. Among all the clichés about Industry 4.0, little focus is on its potential impact on practice-oriented education, like vocational training. Since the development of digitalization is irrevocable, the education system ought to be compatible with the staggering intricacy of the digitized industry. This research centers on the timber industry, reflecting on current carpentry education in Switzerland and Germany. Emphasizing the architectural dimension, it explores innovative ideas for future carpentry school buildings dedicated to the digitized timber construction sector.

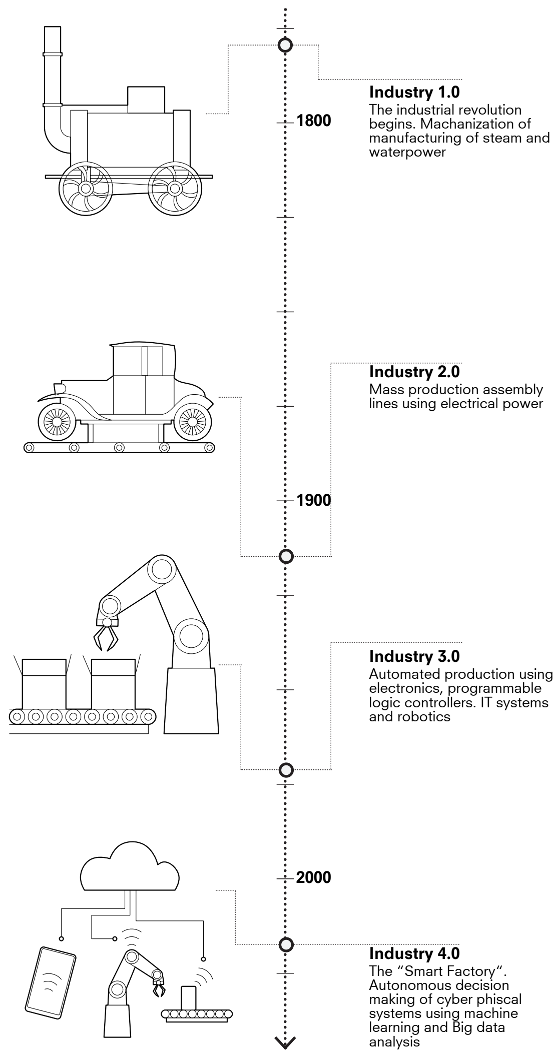

Fig. 1 Industry revolution timeline

1. Frank, Dalenogare, and Ayala, "Industry 4.0 Technologies."
2. Culot et al., "Behind the Definition of Industry 4.0."

Fig. 2 Traditional carpentry workshop

Fig. 3 Automated woodworking

1.2 Problem Statement

In the context of Industry 4.0, where the saws and chisels are supplanted by data-driven robots, the question arises: What and how should students learn in an educational environment shaped by this paradigm shift? Before diving into this question, the development made on the front line of practice needs to be clarified.

Over the years, many researchers have studied off-site robotic production and its contribution to the construction sector[3]. Nevertheless, in the era of digitalization, unlike the boost in manufacturing productivity through data-driven automation, the promise of Industry 4.0 remains more of a buzz than a breakthrough in the construction sector, where productivity levels have remained stagnant for decades[4]. Moreover, as noted by Wagner et al., the efforts for "industrialized building", "prefab", and "modular construction" could only benefit "a rather small proportion of 13.5% of the building construction market in 2030" due to their inflexibility, location dependency, and incompatibility to address ever-changing boundary conditions, and automation systems[5]. While off-site robotic production is incompatible with digitization, the idea of on-site robotic production is worth noting.

Behind the on-site robotic production, there is a straightforward logic, that is, the robots are much smaller and easier to transport than the subassemblies they produce. Following this logic, the so-called "flying factory" concept emerges[6]. In more recent studies, this concept has been developed into a more practical concept of mobile robotic construction[7]. The location-independence and project-based configuration flexibility maximize the applicability and usefulness for industries with narrow profit margins but frequent fluctuation, exemplified by the timber industry.

With the widespread implementation of mobile robotic construction, future timber construction companies will be customized production system providers rather than product providers. This drastic shift of the fundamentals of production needs to be supported by a matching transformation in the educational approach, redirecting from the traditional crafting of wood products to the formulation of various flexible factory systems tailored for different end products. Consequently, the existing learning space and educational framework face substantial challenges, prompting a reconfiguration of school buildings and a call for a heightened level of collaboration between companies and schools.

3. Haukka and Lindqvist, "Modern Flying Factories in the Construction Industry."
4. Changali, Mohammad, and van Nieuwland, "The Construction Productivity Imperative."
5. Wagner et al., "Flexible and Transportable Robotic Timber Construction Platform – TIM."

6. Haukka and Lindqvist, "Modern Flying Factories in the Construction Industry."
7. Wagner et al., "Flexible and Transportable Robotic Timber Construction Platform – TIM."Bygstad et al., "From Dual Digitalization to Digital Learning Space."

INTRODUCTION

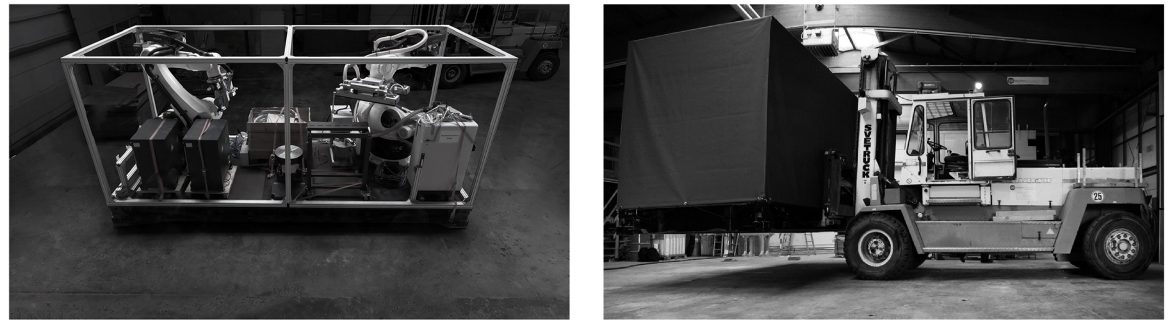

Fig. 4 An exemple of mobile robotic construction concept

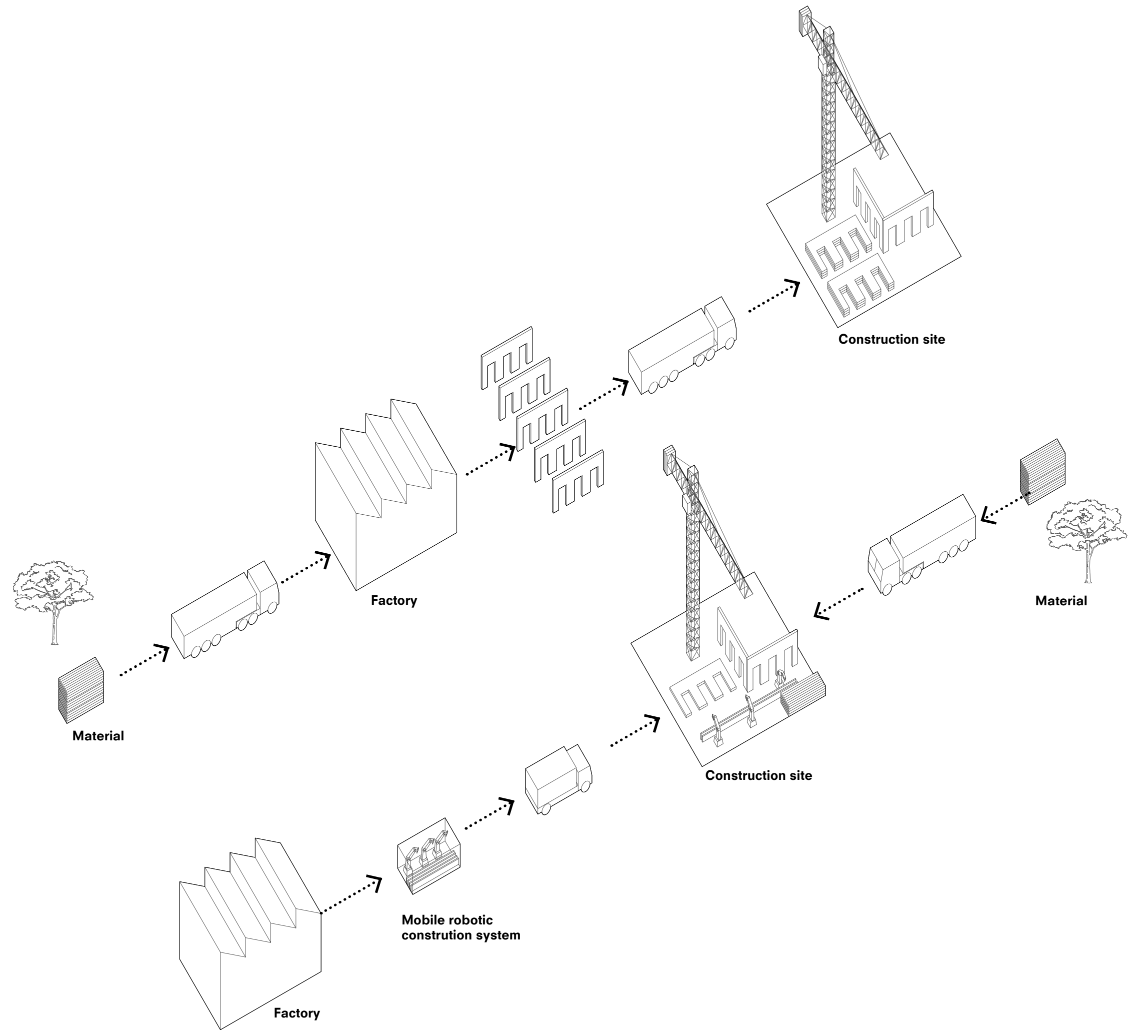

Fig. 5 Off-site production and mobile robotic construction system: the location-independence and project-based configuration flexibility of the latter make it compatible with ever-evolving automation technology and ever-changing market

INTRODUCTION

1.3 Research Question

The aim of this research is to provide a rather undiscussed educational perspective in the discourse of Industry 4.0 – carpentry education could be integrated into Industry 4.0 supply networks, connecting the ever-changing market and ever-evolving technology in the timber construction sector. Like many other application-oriented subjects, for carpentry, companies are as equivalent as the school in terms of producing and imparting knowledge. This trend would be further strengthened in the progress of Industry 4.0. In such a context, spatial aggregation and interplay of timber construction schools and companies would be necessary in the future. Thus, the research question is how to design a building for a conglomeration of timber construction schools and companies. Specifically, **how to inject classrooms into a future smart factory?**

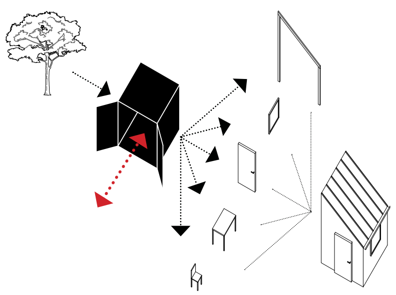

Fig. 6 Unlock the black box for students

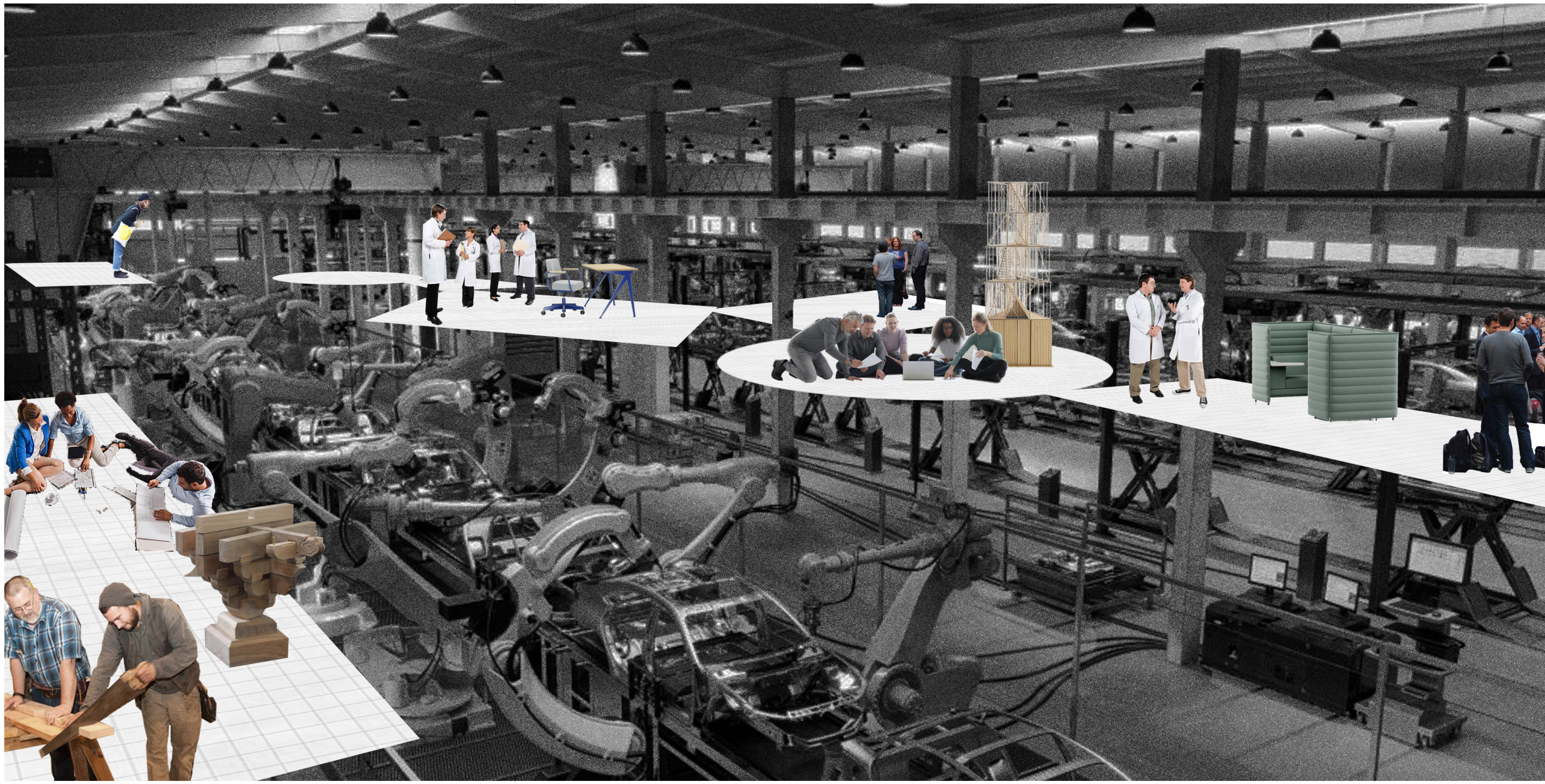

Fig. 7 Inject "classroom" into a future factory

RESEARCH FRAMEWORK

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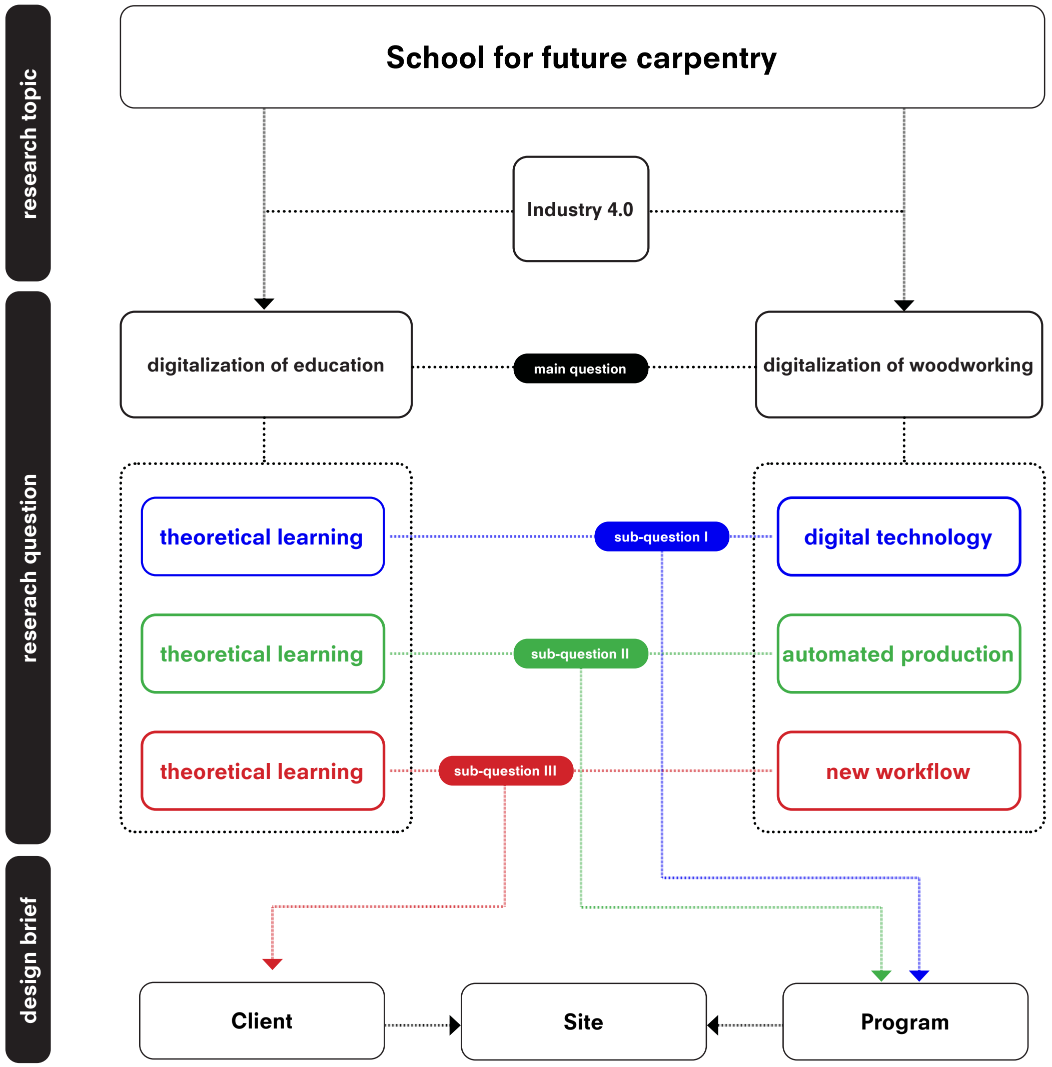

Fig. 8 Theoretical framework diagram

RESEARCH FRAMEWORK

2.1 Theoretical frame work

The theoretical framework of this research is developed based on the "dual digitalization" in higher education proposed by researchers from University of Oslo in 2022[8]. So-called "dual digitalization" refers to the digitalization of education and the digitalization of the subject which is woodworking in the case of a carpentry school.

The former has three aspects that represent three major steps of woodworking education, namely theoretical learning, hands-on learning, and apprenticeship. Likewise, the latter also has three counter aspects, namely digital technology, automated production, and new workflow driven by the "flying factory" system. The integration of these corresponding aspects addresses three preliminary questions underlying the main research question:

- How will the configuration of the learning space (classroom) evolve for learning digital technology?
- How will the automated production affect the carpentry workshop space?
- How will the workflow of the flying factory system change the students' apprenticeship offered by companies?

The program, the client, and the site of the project are derived from these questions, forming the foundation for exploring possible architectural solutions for the main research question.

2.2 Relevance

Because of its ability to store CO2, wood is anticipated to have a crucial role in the journey towards achieving net-zero emissions in the future[9]. However, in Berlin's historical and current reliance on concrete[9], there has been limited space for the establishment of a local tradition of wooden construction. Nevertheless, due to the high volume of forests, the Brandenburg region where Berlin is located has been an important industrial location for the timber industry for several generations[11]. In such a milieu, a new carpentry school that embraces the digital trend is considered to be a powerful stimulation for the development of the Berliner timber construction sector.

8. Bygstad et al., "From Dual Digitalization to Digital Learning Space."
9. Woodard and Milner, "Sustainability of Timber and Wood in Construction."
10. Winter, Schröter, and Fidaschek, "The German Cement Industry as a CO2 Source for Other Industries."
11. "Wälder Brandenburgs."

RESEARCH METHODS

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To address the research question in a tangible and practical manner, this research is design-based. The design process of an imaginary future carpentry school project in Berlin, Germany will be the medium for discussion, and the design result will embody the final idea of the research question. Thus, defining the program, the client, and the site – usually considered three indispensable prerequisites of architectural design - are treated as three distinct topics, each with its varied methods.

3.2 Client

There are two consecutive methods used to define the client framework of the project. First, by case studies of pertinent existing institutes both in Berlin and worldwide, a basic framework of the client is summarized. This is followed by a reflection on it based on the literature review of the new workflow of the "flying factory" concept. With the upgrade of the whole supply chain, the significance of every stakeholder is redefined as well as their interconnections. As a result, a well-structured client framework that supports the new production mode in the Industry 4.0 era is proposed.

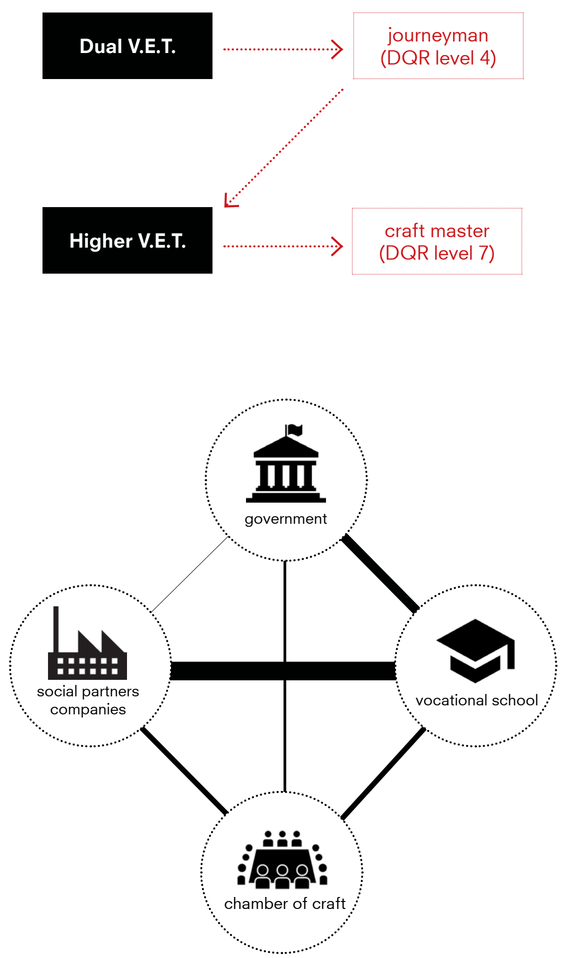

Fig. 9 The vocational educational training system in Germany

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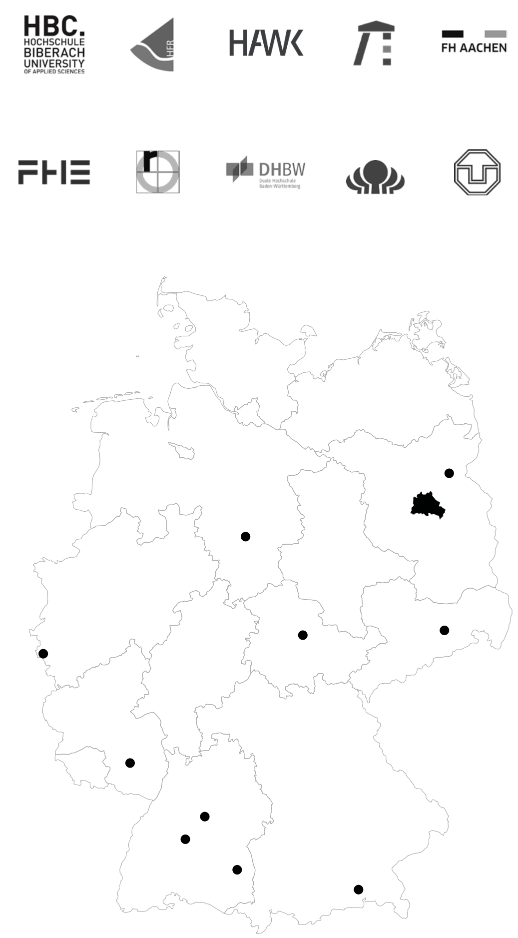
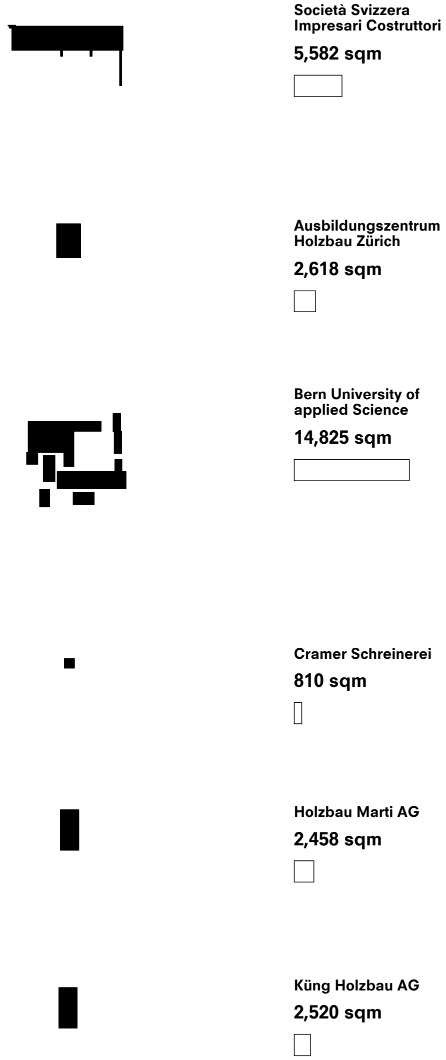


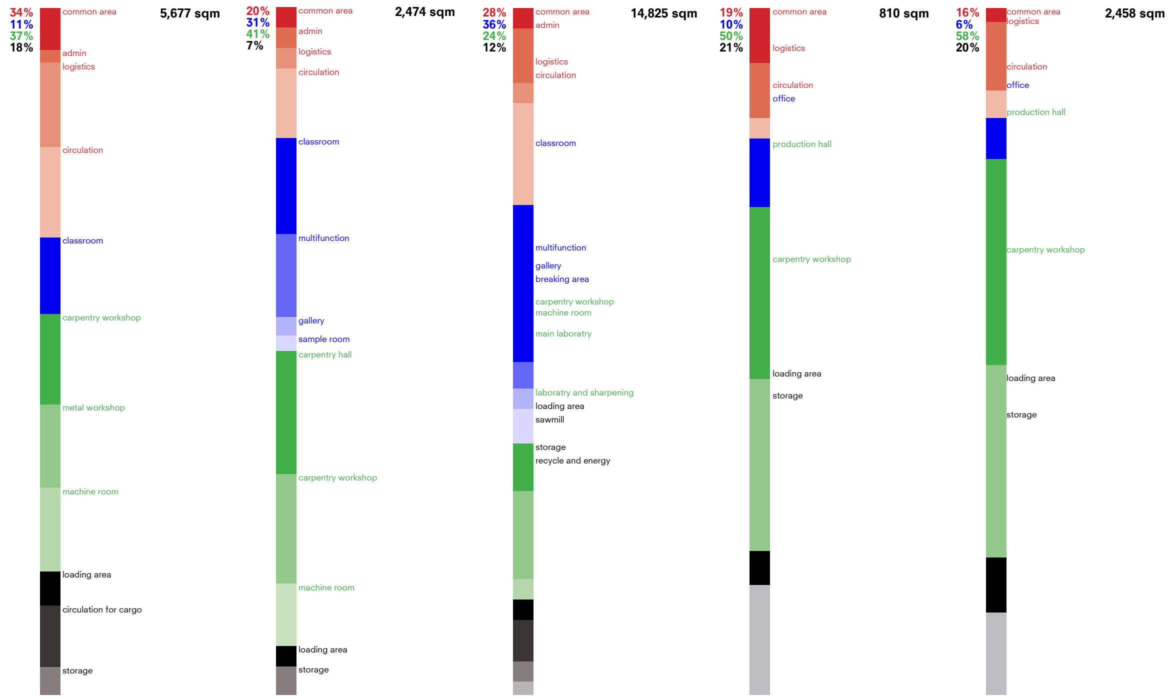
Fig. 10 Higher education of timber industry

3.1 Program

The program is carried out by case studies of pertinent contemporary built projects. There are three categories of cases: carpentry school, carpentry factory, and evocative ones. The first two are used to distill the benchmarks for the programs. Therefore, the programs' proportion and their planar layout of the cases are analyzed in detail. Through comparison between the analytical results of different cases, a quantified program bar could be drawn. Unlike the first two categories, the last category, namely the "evocative ones" is not confined to certain typology. These cases are selected and analyzed based on their intriguing relevance to either the integration of theoretical learning and digital technology or the integration of hands-on learning and automated production. Afterwards, the program bar and program relationship are revised to fit in Industry 4.0 context.



RESEARCH METHODS



Centro di Formazione Professionale

Architect: Durich Nolli
August, Switzerland
GFA: 5,582 sqm

Ausbildungszentrum Holzbau

Architect: Peter Moor
Zürich, Switzerland
GFA: 2,618 sqm

Bern University of applied Science

Architect: Meil Peter
Bienne, Switzerland
GFA: 15,147 sqm

Cramer Schreinerei

Architect: Brandlhuber
Cologne, Germany
GFA: 810 sqm

Holzbau Marti AG

Architect: AMJGS Architektur
Matt, Switzerland
GFA: 2,458 sqm

Fig. 11 Case studies overview

3.3 Site

Based on the program and the client, three site criteria are set as follows:

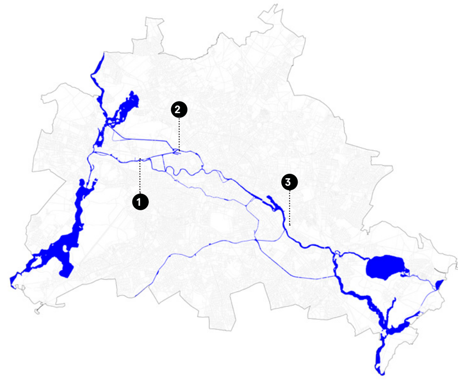
- Sustainable freight transport - along the main inland waterway of Berlin
- Industrial yet inhabitable - in an industrial area yet has good access to green area and public trasnportation
- Build to impact - proximity to future construction hotspot

1. Siemensstadt: Surrounded by logistics centers, a construction material market, and Siemens Energy, the site includes a disused railway bridge leading to a U-Bahn station within a 15-minute walk. The bridge has potential for renovation as part of the school.

2. West Hafen: Situated in Berlin's main port, managed by BEHALA, the site features two logistics centers, a recycling district, and a functional harbor, providing optimal support for the carpentry school's freight transport. Its proximity to an S-Bahn and U-Bahn node ensures excellent accessibility.

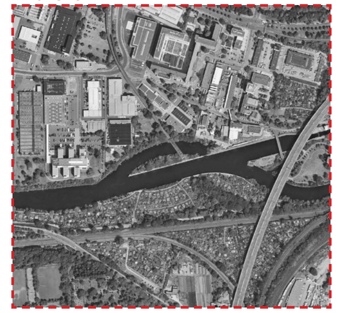
3. Klingenberg: Occupied by six disused bunkers from a nearby power plant, the site near Klingenberg Hafen offers good waterway access. However, its reachability is less ideal due to the absence of a nearby mobility hub.

RESEARCH METHODS

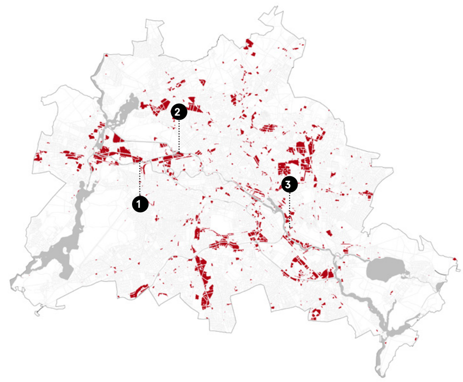


Site criteria mapping - inland waterway

Final site

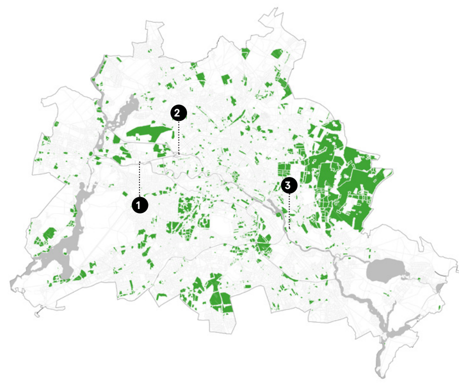


Sustainable freight trasport: + + + +
Industrial yet inhabitable: + + + +
Build to impact: + + + + +



Site criteria mapping - industrial area

Sustainable freight trasport: + + + +
Industrial yet inhabitable: + + +
Build to impact: + + +



Site criteria mapping - future construction hotspot

Sustainable freight trasport: + + + +
Industrial yet inhabitable: + +
Build to impact: + + + + +

DESIGN BRIEF

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4.1.1 Client overview

The main client of the project is the Eberswalde University for Sustainability. As the only institution that provides higher education on timber technology, Eberswalde University will relocate its timber department to Berlin, aiming to explore the Industry 4.0 of the timber sector. The institutes in Berlin could collaborate with Eberswalde to link the most advanced technology and the down-to-earth experiment.

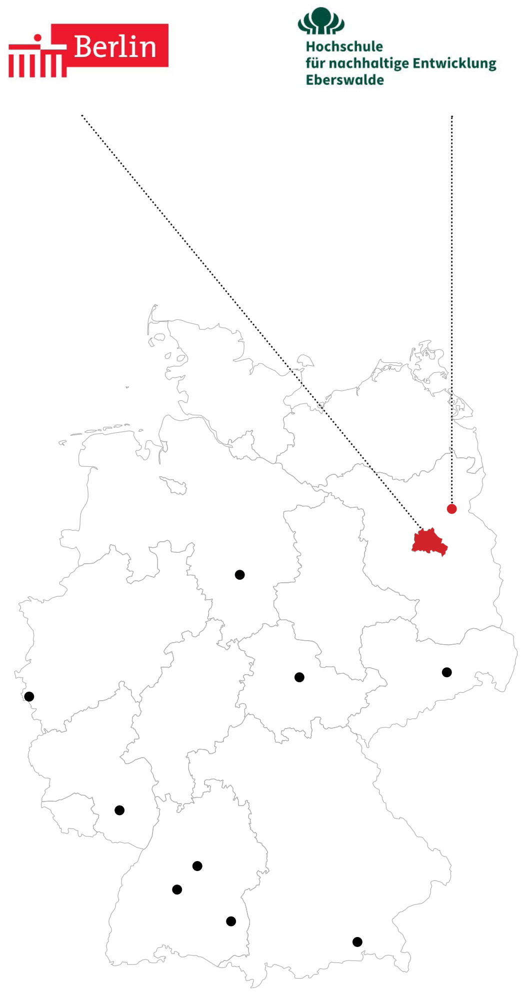


Fig. 12 Two main clients

4.1.2 Number of users

Students: 500
* Bachelor of wood technology
* Master of wood technology
* Apprentice
* Carpentry Journeyman (DQL-4)
* Carpentry Master (DQL-7)

Researchers: 120
Tearchers: 60
Employees: 30
Practitioners: 100

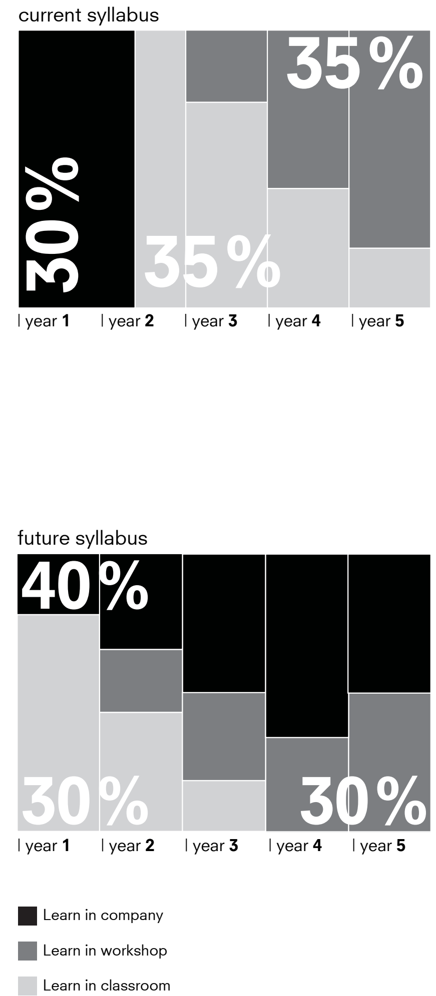
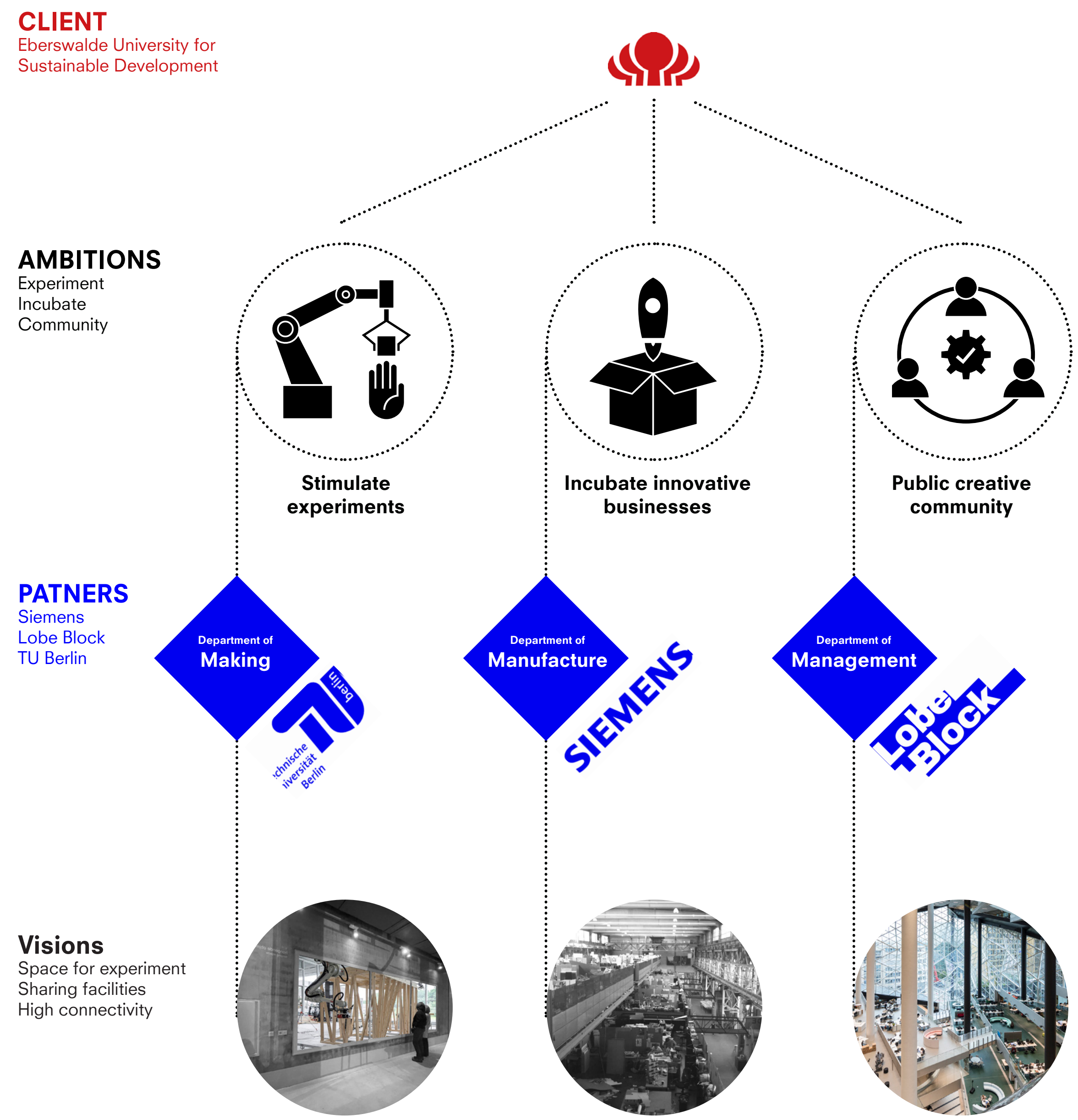


Fig. 13 Current syllabus and future one

4.1.1 Ambitions and partnership

With the aim of building a school for the timber Industry 4.0, the school has three ambitions: to stimulate experiments, to incubate innovative timber businesses, and to build a creative community. Three departments are set up to address the three ambitions correspondingly. Moreover, each department has a partner to achieve the goals. The Department of Making has TU Berlin as a partner, who has strong academic and research resources. Technology developed in TU Berlin's lab could be tested and prototyped at the new Elberswalde University. The Department of Manufacturing has Siemens as the partner. With its experience in automation and business-to-business service, Siemens will be the provider and consultant of the facilities in the school. Additionally, the facilities are open to small timber businesses. Last but not least, the Department of Management has Lobe Block as a partner, who is an investor focusing on building a creative community through the curation of programs.



4.2.1 Program understanding

The program of the carpentry school is categorized into 5 clusters: **COMMUNAL, LEARNING, MAKING, LIVING,** and **MATERIAL**.

The **MAKING** section includes the most essential space of the project. It consists of one section dedicated to advanced technology and another section of more traditional craftsmanship. The former has a robotic production lab equipped with a crane and gigantic robots, as well as an experiment hall which is used to test and assemble. The latter has a carpentry machine room for basic woodworking, and a workshop for assembly and hands-on practice.

According to some advanced reference, some dimensions are suggested:

- The height of the robotic production lab should be no less than 8.5 meters.
- The bay span of the carpentry machine room and workshop should be no less than 9 meters

The school also offers housing that could be also used as atelier for students and young professionals.

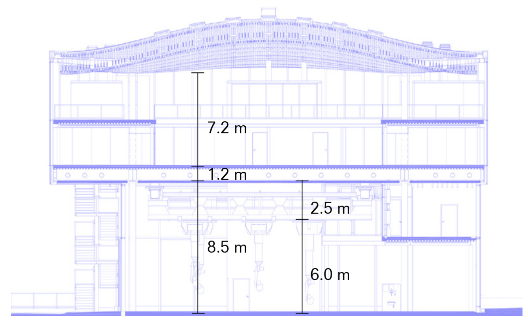
COMMUNAL
common area
circulation
service
sports hall

LEARNING
classroom
sample room
multifuctional room
gallery
breaking area
admin

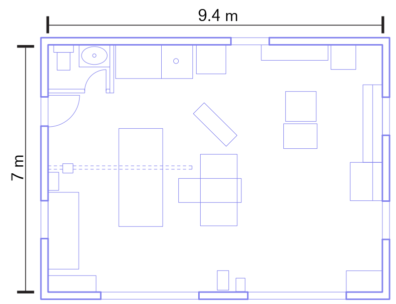
MAKING
robotic production lab
experiment hall
machine room
workshop
- bench room
- paiting
- grind
- spray
- lasercut
- CNC

LIVING
work-life unit
student housing

MATERIAL
loading
sawmill
storage
recycle



The robotic lab of ITA, ETH



The minimal size of a carpentry workshop

Fig. 14 Robotic lab of ITA

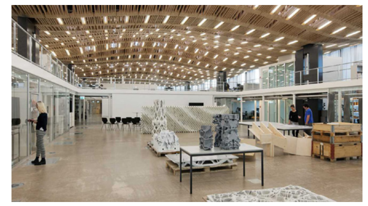


Fig. 15 Assembly hall of ITA

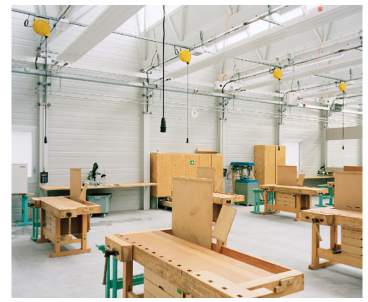


Fig. 16 Carpentry workshop at SSCI center

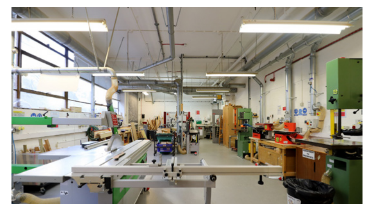


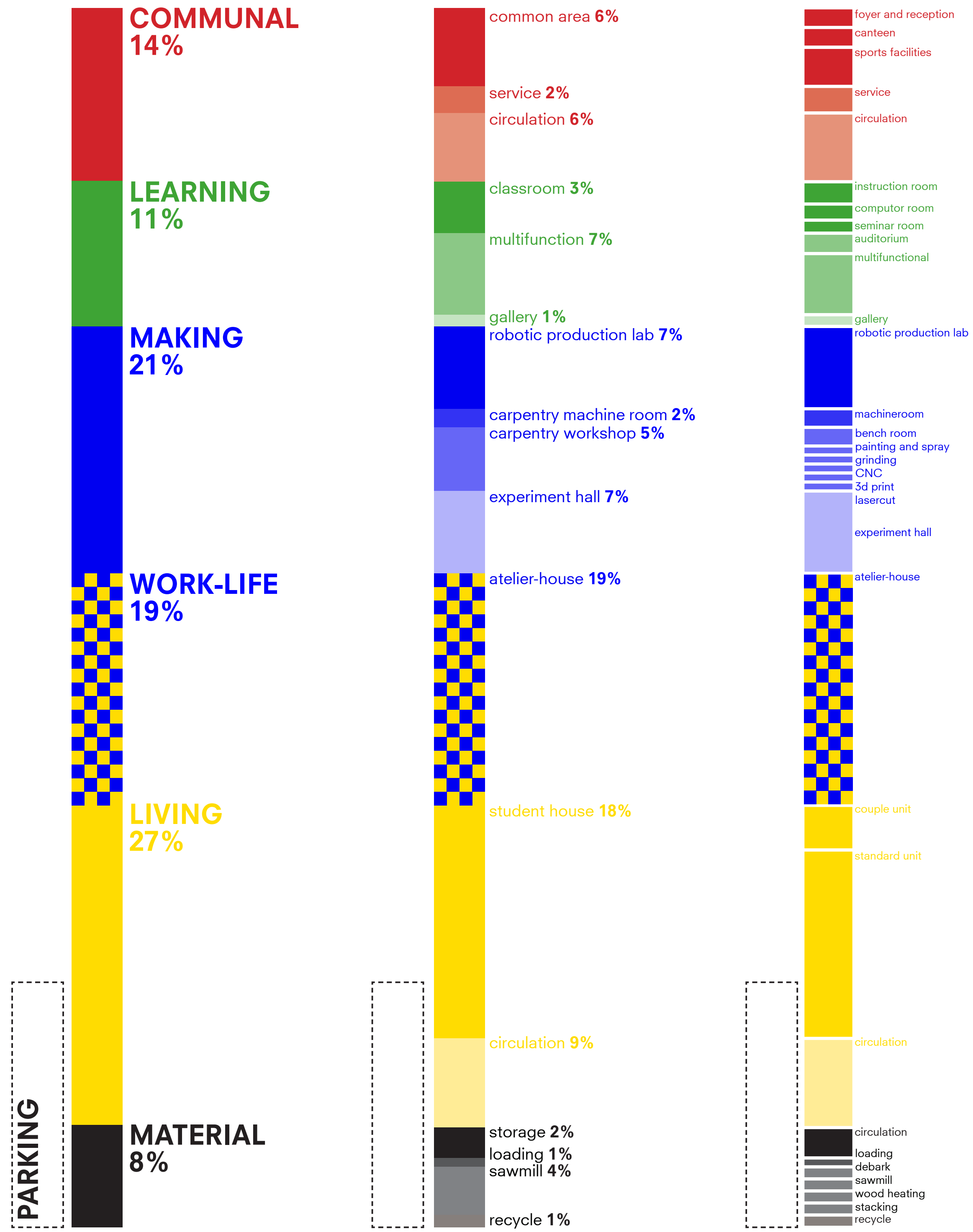
Fig. 17 A typical carpentry machine room

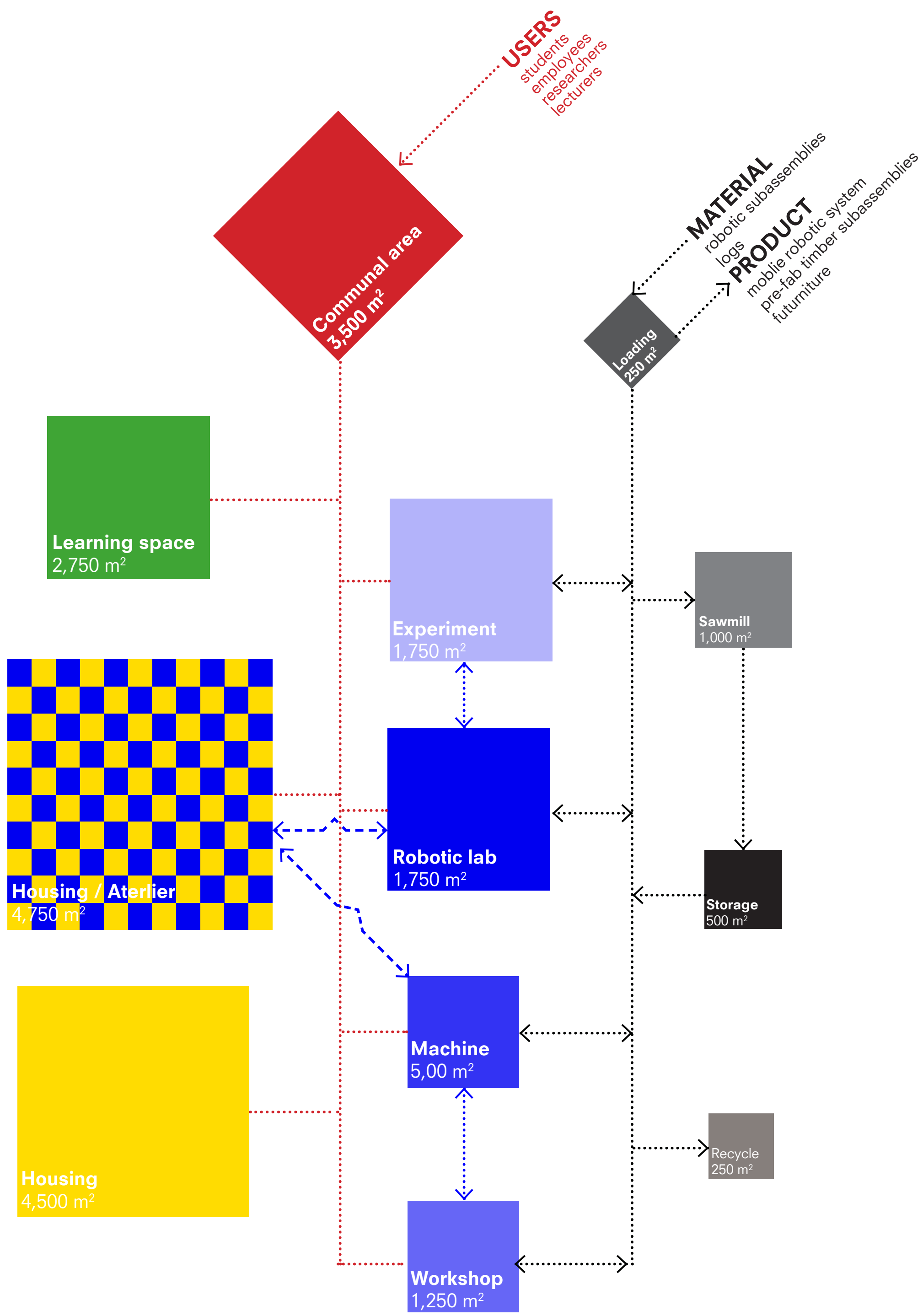
4.2.2 Program bar

The total area of the building is 25,000 m², without taking 5,000 m² parking into account. The following table contain the defined usable areas.

Total usable area	**25,000 m²**
*foyer and reception	100 m²
*canteen	650 m²
*sports facility	650 m²
service	500 m²
circulation	1,500 m²
classroom	750 m²
*multifunctional room	1,750 m²
*gallery	250 m²
robotic production lab	1,750 m²
carpentry machine room	500 m²
carpentry workshop	1,250 m²
experiment hall	1,750 m²
*atelier - house	4,750 m²
*student house	4,500 m²
circulation in the housing section	2,250 m²
material storage	650 m²
loading area	100 m²
saw mill	1,000 m²
recycle	250 m²

Functions marked with an asterisk are flexible and should be decided in the design phase.





4.2.3 Program relationship

The communal area and the loading are two "foyers" of the building. The former is a "foyer" for people, and the latter is one for materials. The circulation of people and materials is separated. The cluster of dwelling and the cluster of materials are connected with the "making cluster" through general circulation separately. Besides the general circulation, the work-life programme should have a direct connection with the making clusters. The material cluster is a micro-scale extrapolation of the industrial process of timber products.

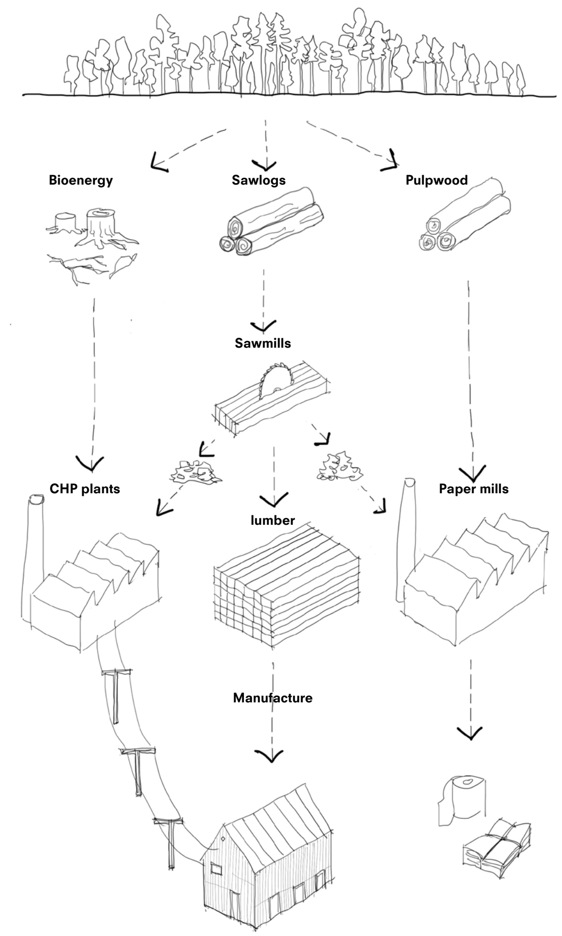


Fig. 18 Timber industry in general

4.3.1 Site overview

The site is located in Siemensstadt, a former region developed by the big corporation through various industrial production. The site covers an area of 2.98 ha, adjoining factories, logistics centre, and office buildings. It is bordered by the Spree River on the south, and the other side of the river is covered by allotments and huts. The site can be easily accessed via the metro system of Berlin, but it lacks adjacent public facilities such as a sports field.

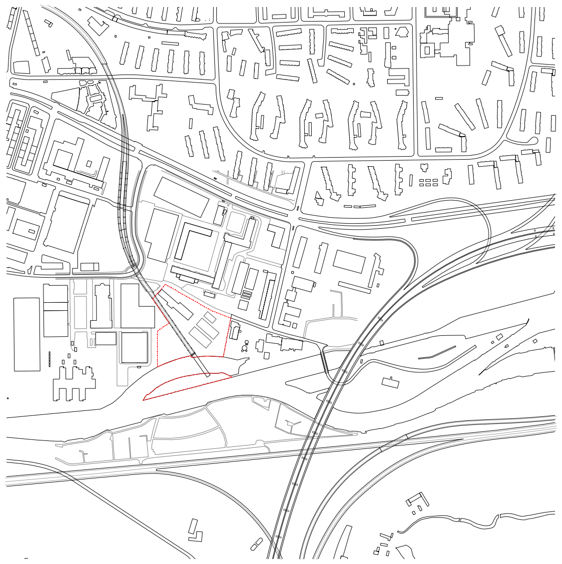
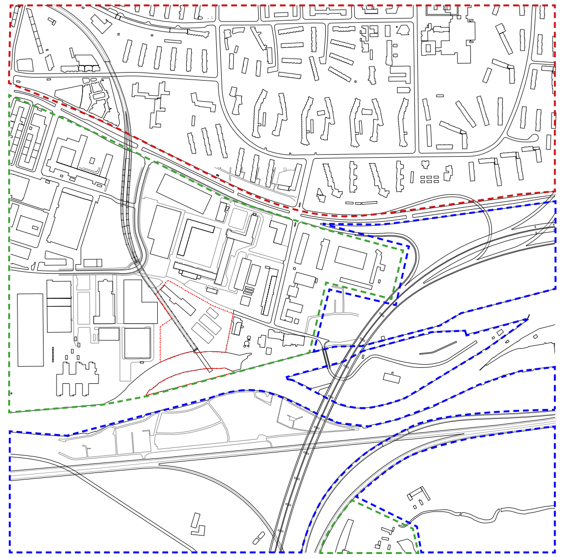
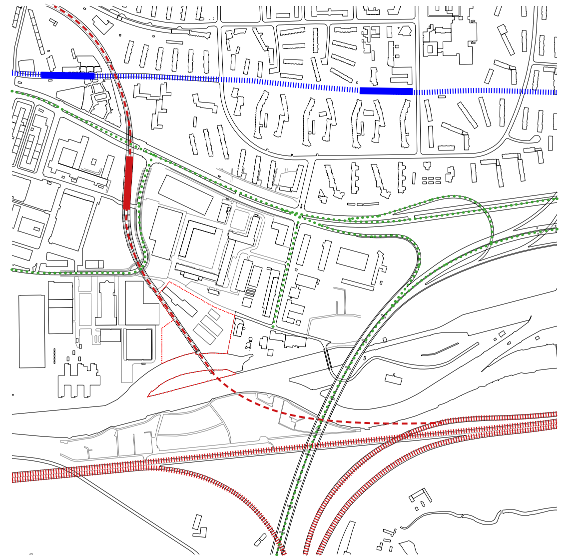


Fig 19. The site

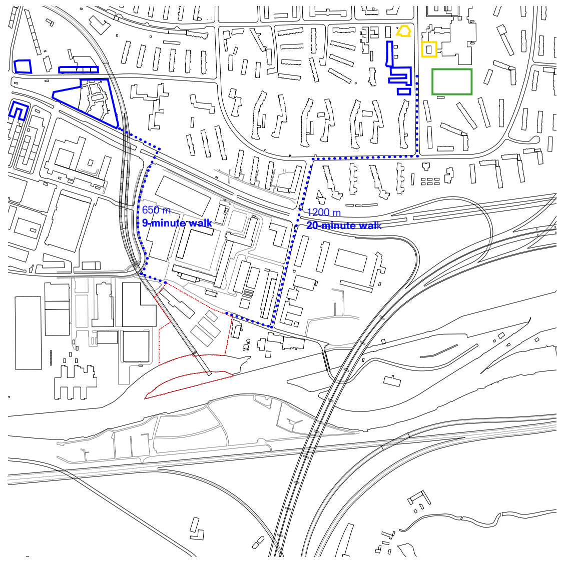
DESIGN BRIEF



Urban context



Transportation



Public facilities

Industrial area
Residential area
Allotment & Green area
road
S Bahn
Planned S Bahn
U Bahn / tram
Library, church
Football field
Commercial

4.3.2 History of the site

The site is characterised by a section of disused waterway of the Spree and the disused Siemens Bahn viaduct. Steeped in history, the waterway was gradually regulated. And with the construction of the new Charlottenburg lock in 2003, the eerie island was created.

Fig 20. Timeline of the waterway evolution from central Berlin to Spandau

The Siemensbahn is an old rail line that used to commute employees of Siemens. It was destroyed in the war. After the war, with the relocation of Siemens, the Siemensbahn was shut down. In the foreseeable future, Siemensbahn will remain intact.

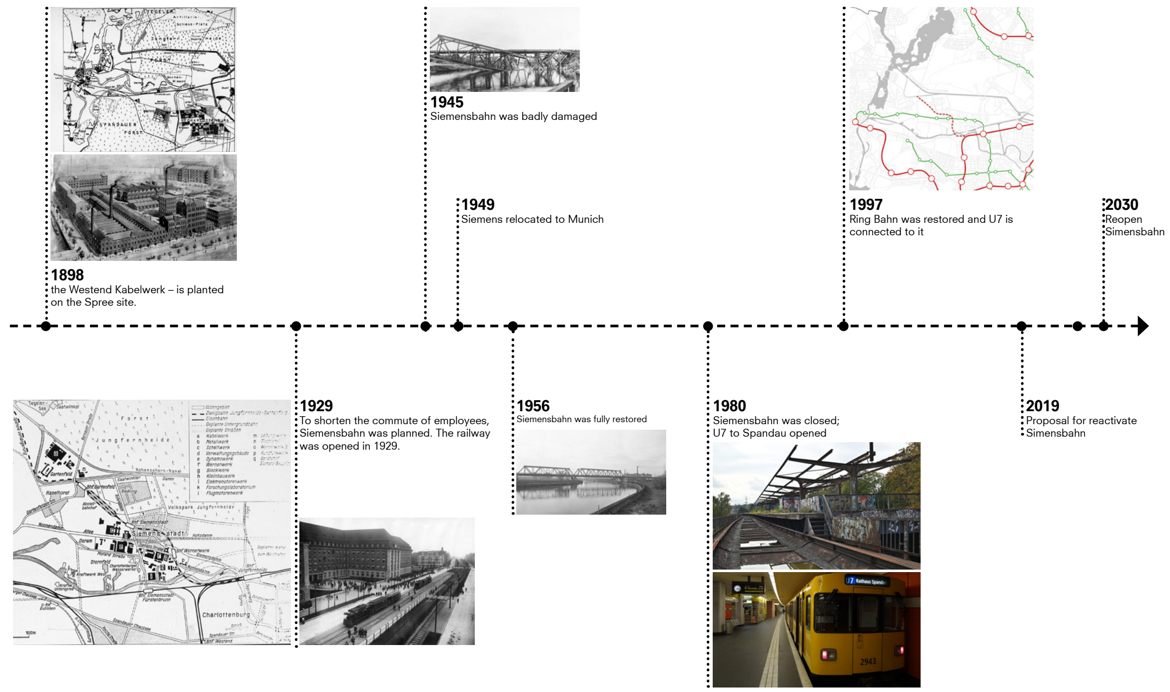
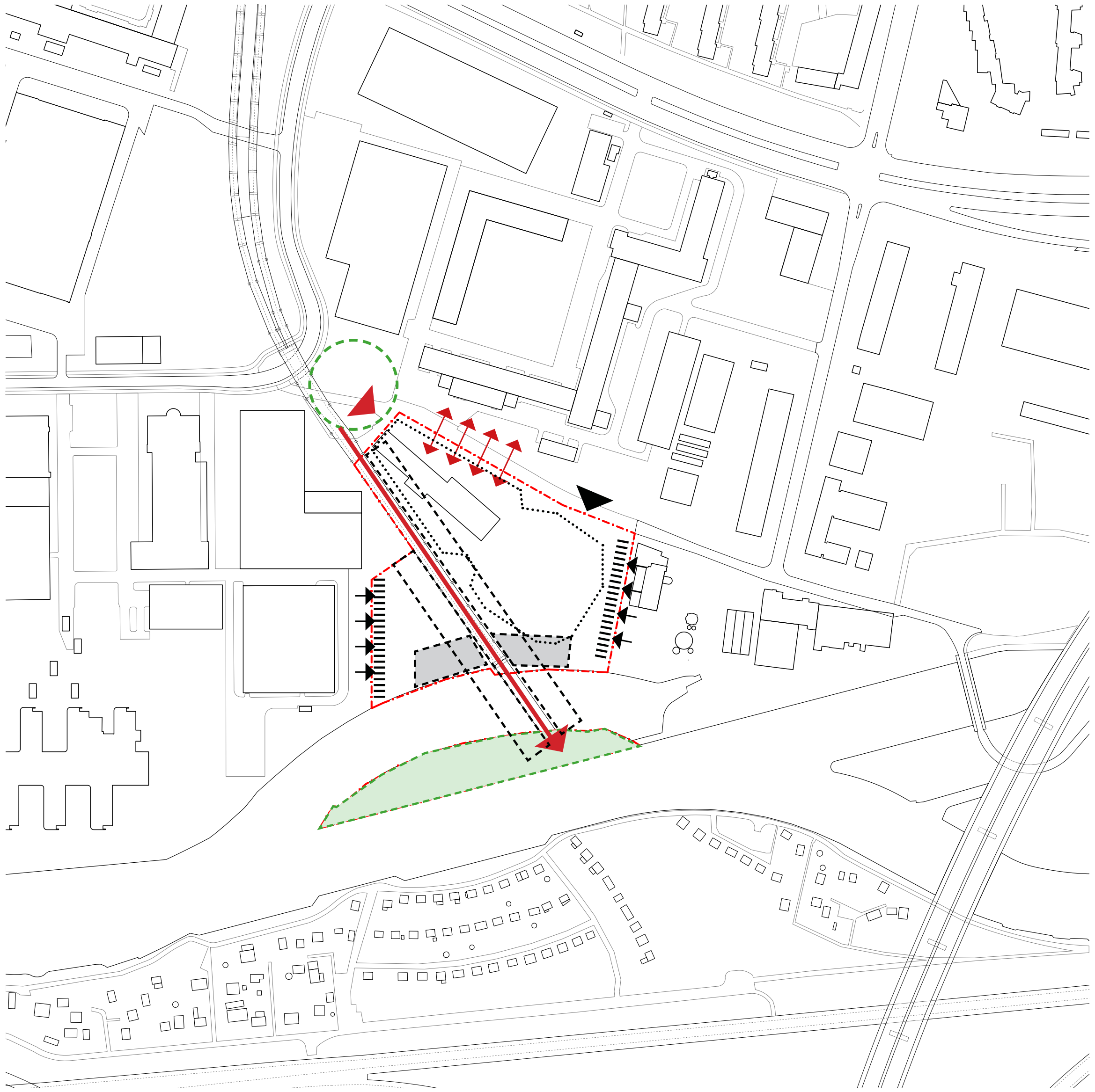
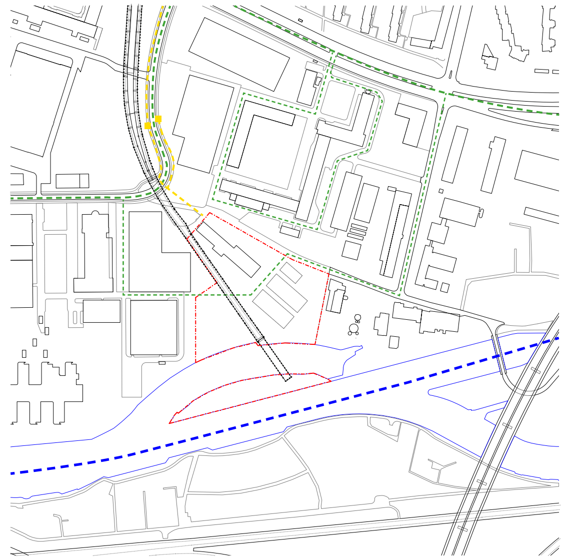
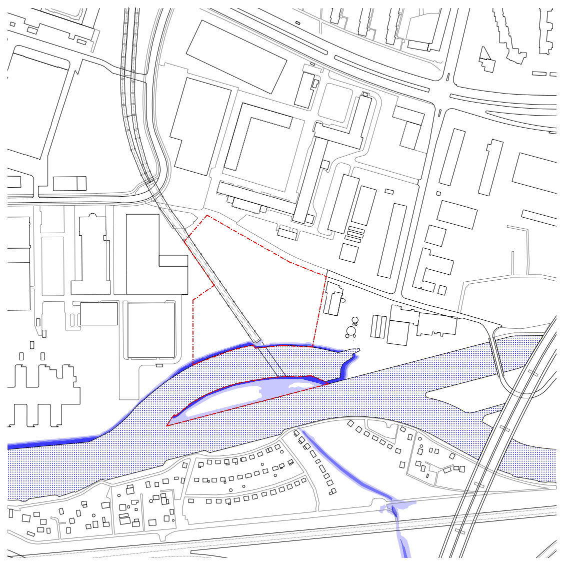


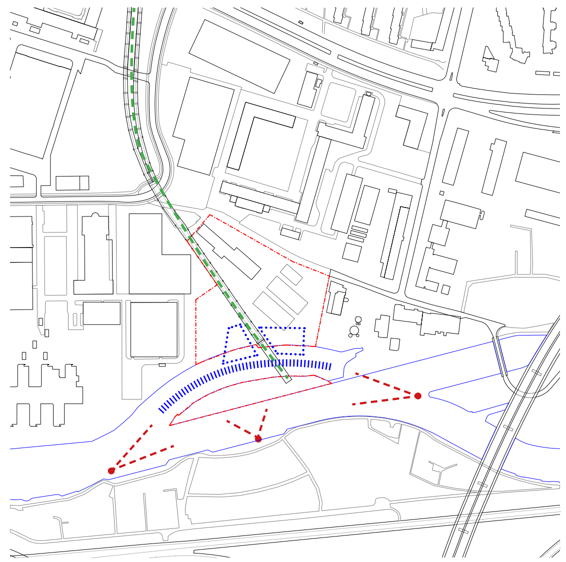
Fig 20. Timeline of Siemensbahn

4.3.3 Site analysis





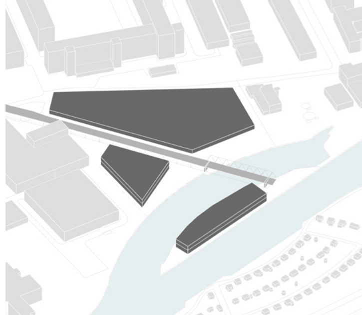




4.4 Massing study

Coverage

BCR **65%**



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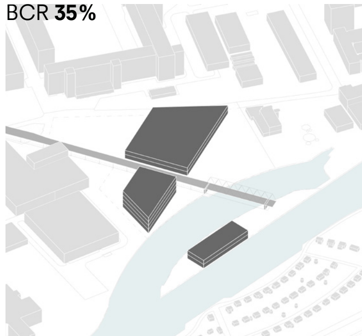

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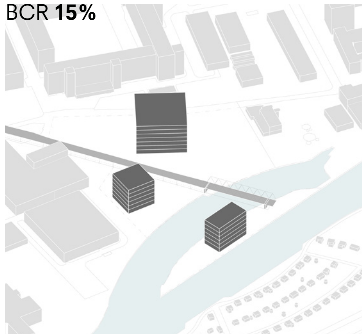
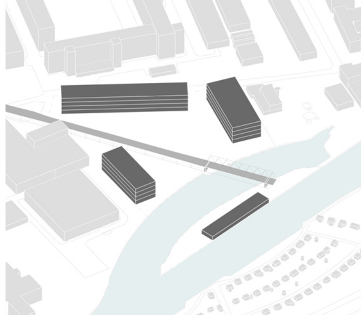


Open space

Enclosed



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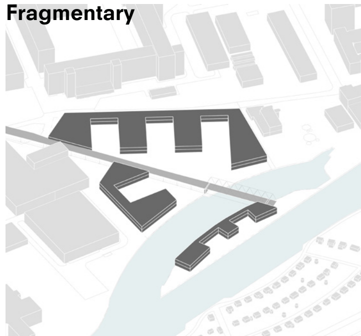

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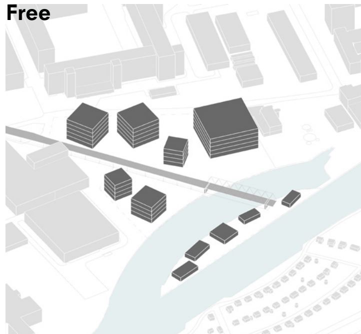
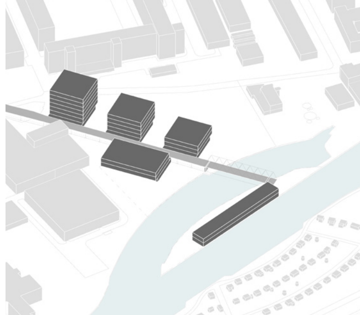


Relationship with the viaduct

Attached



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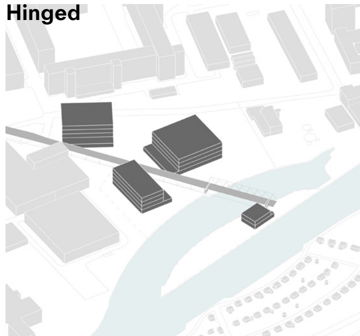

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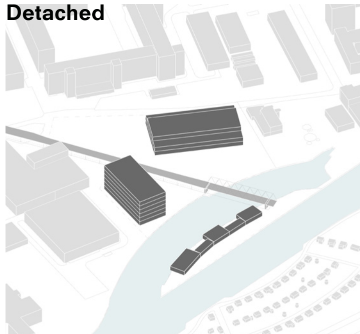
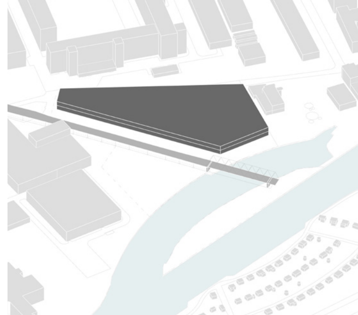


Coverage

BCR **70%**



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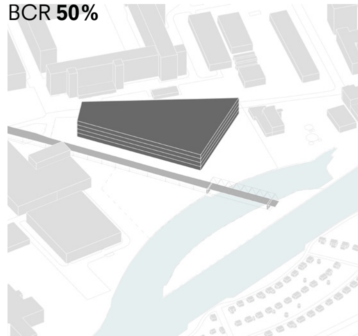

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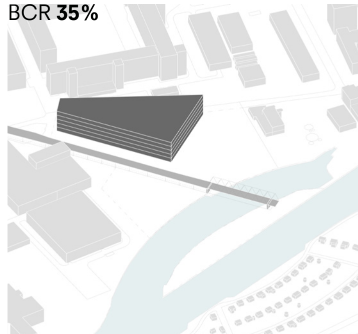
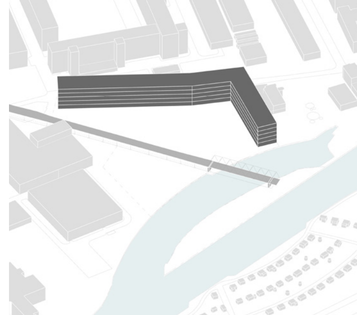


Open space

Enclosed



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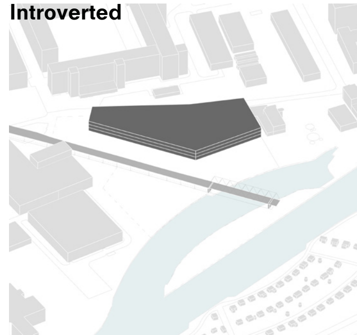

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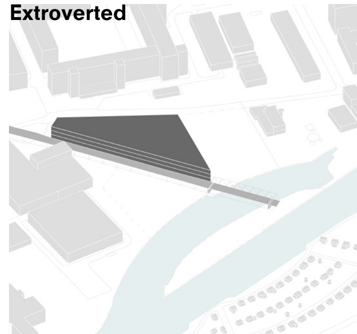
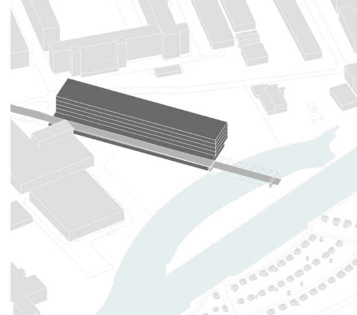


Relationship with the viaduct

Attached



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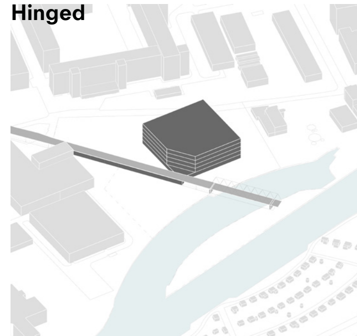

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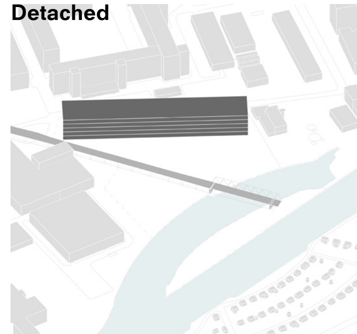
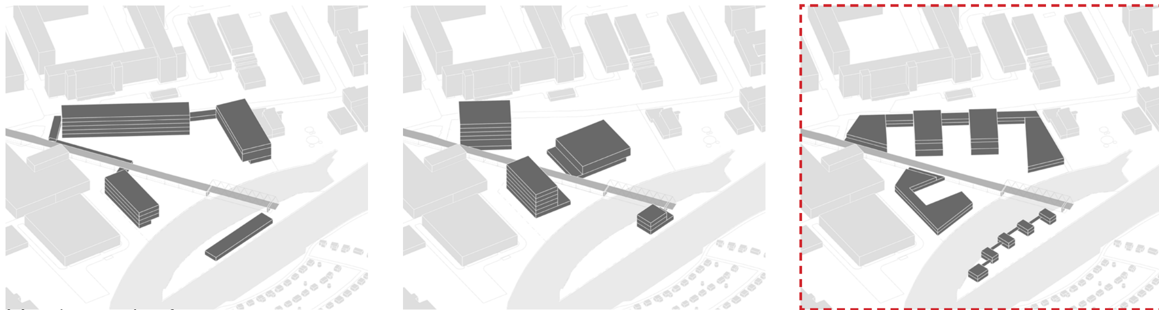
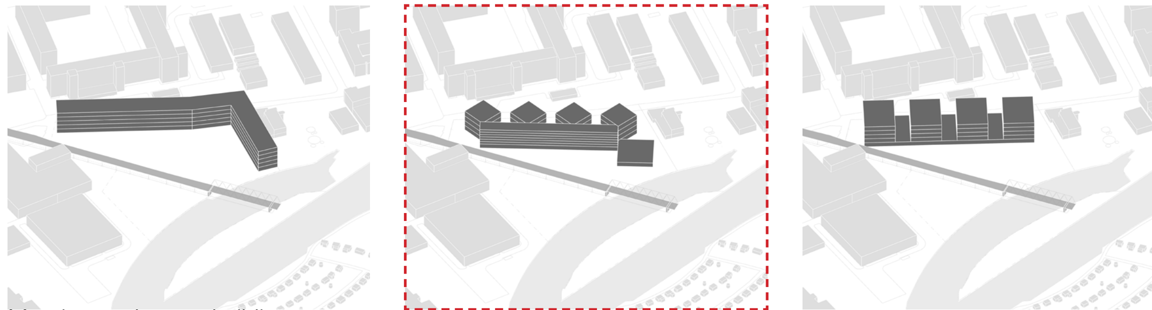


4.4 Massing study

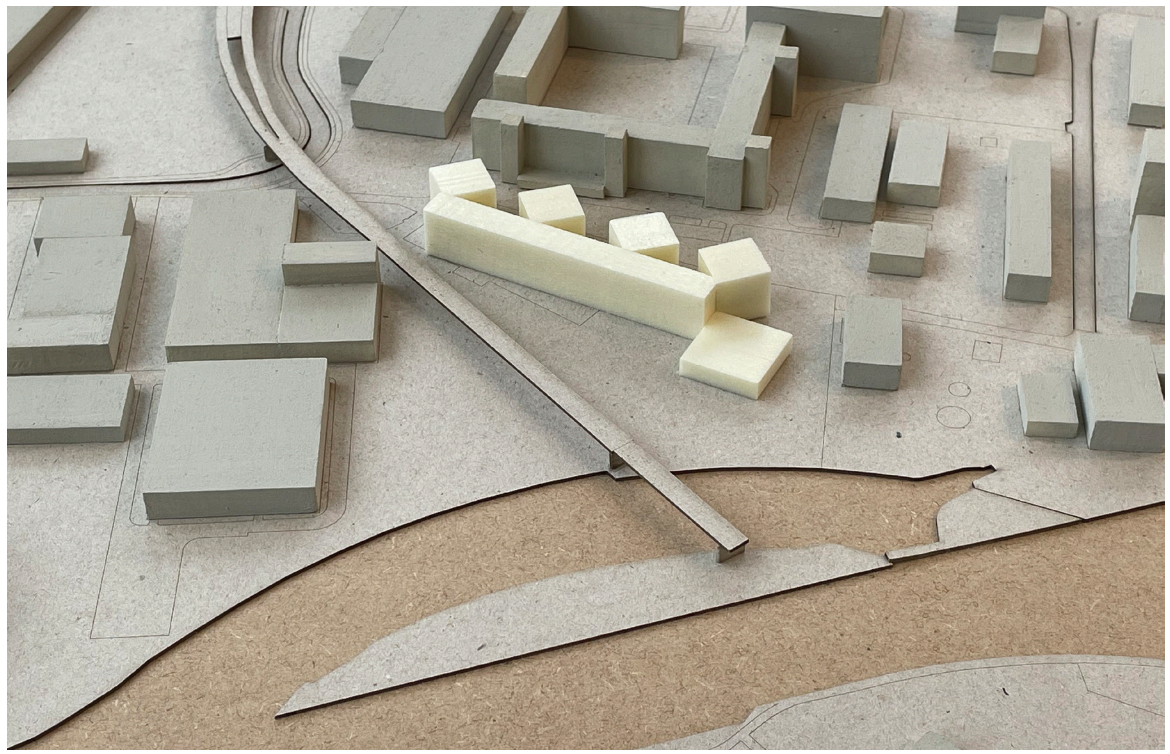


Massing study - fragmentary strategy

Massing study - fragmentary strategy



Massing study - one building strategy



Massing study - one building strategy

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05

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5.2 Figures

Fig.1. Created by author

Fig.2. Edward Barnsley's Workshop c.1936.

Fig.3. Dörfler, Kathrin, Norman Hack, Timothy Sandy, Markus Giftthaler, Manuel Lussi, Alexander N. Walzer, Jonas Buchli, Fabio Gramazio, and Matthias Kohler. "Mobile robotic fabrication beyond factory conditions: Case study Mesh Mould wall of the DFAB HOUSE." Construction robotics 3 (2019): 53-67.

Fig.4. Wagner, Hans Jakob, Martin Alvarez, Ondrej Kyjanek, Zied Bhiri, Matthias Buck, and Achim Menges. "Flexible and Transportable Robotic Timber Construction Platform – TIM." Automation in Construction 120 (December 2020): 103400. https://doi.org/10.1016/j.autcon.2020.103400.

Fig.5. Created by author

Fig.6. Created by author

Fig.7. Created by author

Fig.8. Created by author

Fig.9. Created by author

Fig.10. Created by author

Fig.11. Created by author

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Fig.13. Created by author

Fig.14. Photograph: Andrea Diglas / ITA/ Arch-Tec-Lab AG

Fig.15. Photograph: Andrea Diglas / ITA/ Arch-Tec-Lab AG

Fig.16. DANIELA DROZ & TONATIUH AMBROSETTI

Fig.17. https://3dworkshoplcc.arts.ac.uk/books/woodwork-essential-info/page/woodwork-machine-room-essential-info

Fig.18. Created by author

Fig.19. Created by author

Fig.20. Created by author