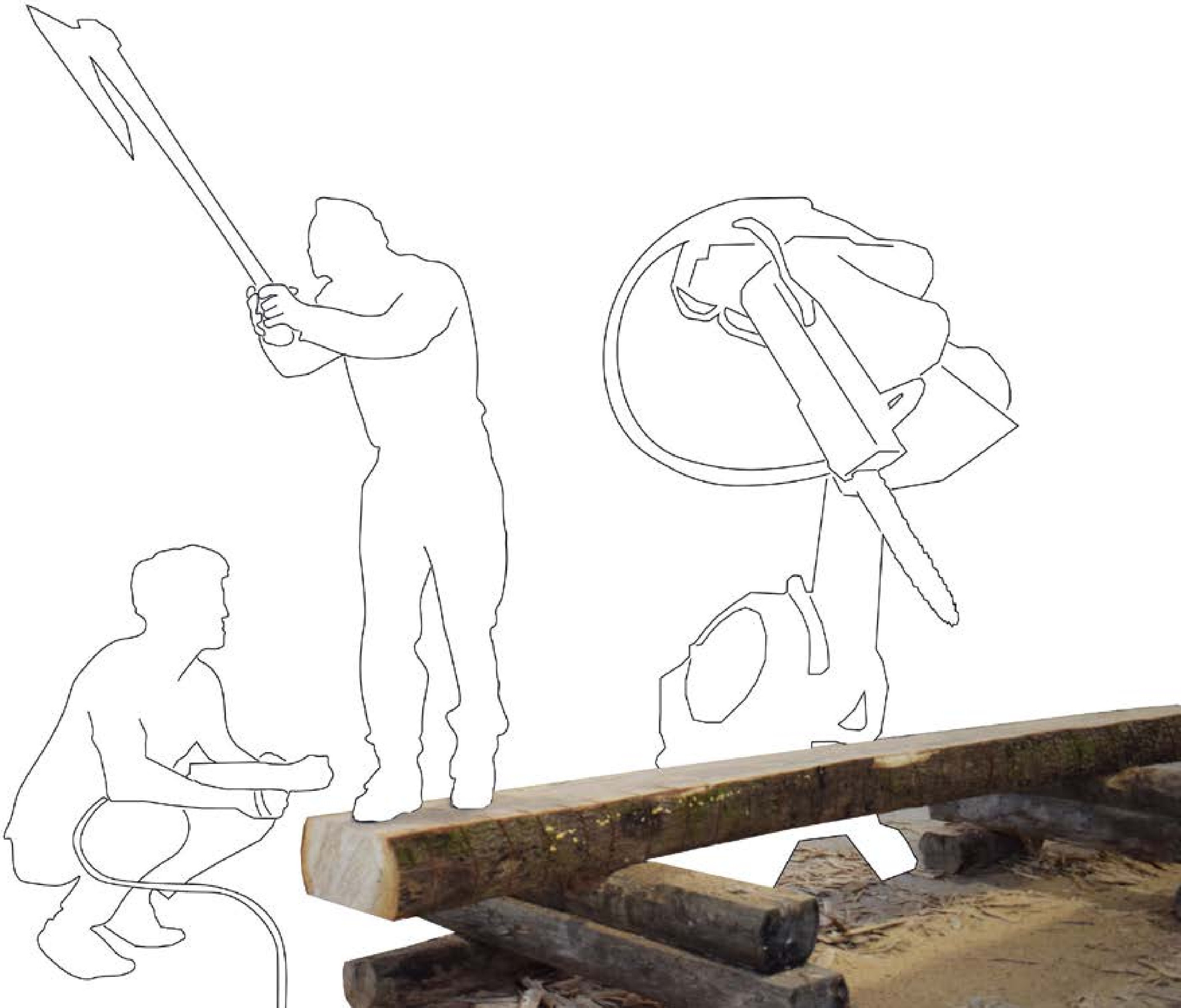
DIGITAL WOODCRAFT

Building Sustainably with the Synergy of Traditional Craft and Modern Technology

Alberto Per Johnsson



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Theoretical Statement for the Master Project in Architecture.

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This is a digital rendition of the Digital Woodcraft essay. The text underwent slight revisions. The PDF is interactive, allowing readers to navigate throughout chapters. The table of contents features clickable titles for easy access to desired chapters, and page numbers can be clicked to return to the table of contents.

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Table of contents

Abstract

“Nowadays, all Swiss architecture schools are focusing on training Students to win competitions. The real life of the construction profession is, however, not just about that. Simply learning how to build well and sustainably is already more interesting than overburdening students with concours they are not sure to win. In consequence, contractors and construction project managers abound.”

Those were the words of Jean-Marc Ducret, civil engineer and Managing Director of the construction company JPF-Ducret SA, when I visited their factory in Yverdon.
Since the 15th century, the professionalization of architects has marked a significant shift in dominance within the construction field. Through the utilization of drawings and the cultivation of privileged relationships with clients, architects assumed authority over the construction process. This transformation resulted in a loss of autonomy for artisans and builders.
A few centuries later, the Industrial Revolution catalyzed the emergence of new professions, such as contractors and construction companies. These entities not only assumed the authority held by architects but also integrated the construction knowledge that was once the domain of artisans. Consequently, architects became primarily focused on drafting, while the traditional techniques of artisans disappeared.
This highlights the importance of reevaluating and redefining the roles of architects and artisans in contemporary practices.

How can we reintegrate architects and artisans into the current industrial paradigm, bridging the gap between traditional craft and modern industrial processes?

As the grandson of a carpenter, my inclination draws me to explore the timeless craft of wood-making—a practice as ancient as humanity itself. Today, it is experiencing a resurgence, reclaiming its role as a core process in the industry. This research will delve into the evolution and potential of wood processing, examining its journey through both pre-industrial and industrial periods. The focus will be on two dominant processes: Traditional Green Wood Squaring and Industrial Glulam Processing.

The exploration of green wood squaring will be drawn from the resurgence of this practice, notably observed during the reconstruction of Notre Dame. Multiple site visits were conducted to gather informations for this study:
A visit to the forge of Serge Turberg in Malleray, Switzerland.
A visit to the “Atelier de la Grande Oye”, Lods, France

The investigation into industrial wood processing will draw insights from the construction of one of the initial wooden towers in Switzerland. Multiple site visits were conducted to gather informations for this study:
A visit to the Sawmill “Scierie-Zahnd” in Ruyeres, Switzerland
A visit to the “JPF-Ducret factories” in Orges and Yverdon, Switzerland

Artisans and architects can be reintegrated through on-site practices, merging traditional skills with contemporary methods. Current processing faces challenges in waste management, transport, increased energy consumption, and higher costs. Hand tools offer a potential solution by efficiently handling waste and preserving artisan skills. While manual practices may be slower, strategic use of machines and automation can enhance efficiency. This study advocates for the reintegration of green wood squaring into contemporary processes, emphasizing the synergy between traditional craftsmanship and modern technology.

Introduction

To reintegrate artisans and architects it is important to contextualize the problems that exist in the actual industrial paradigm:

Skills
Waste
Distance

The introduction will explore them and initiate a solution and a methodology.

I. Skills

Contemporary construction and processing are characterized by a diminished engagement with the skills and autonomy of both artisans and architects.

The Artisan

During the period known as the Middle Ages, situated between the Classical era and the Renaissance, construction took on a decentralized and collective nature. It heavily relied on oral exchange, templates, and established traditions.[1]
Craft and construction were protected bodies of knowledge exclusively passed down from master to apprentice during this period. Artisans convened in guilds to collaboratively discuss building methods and geometrical problem-solving techniques.[2]
During this period, buildings were erected through oral communication within a collective system involving master builders, craftsmen, and patrons. The construction process lacked specific encoding in plans and relied on shared knowledge and collaboration.[3] All artisans were intricately engaged in both the design and construction processes, fully immersed in the practical aspects of construction and the characteristics of the materials used.[4]

The Architect

During the economic growth of 15th-century Italy, prosperous merchants with private wealth began to demand more stylish and monumental buildings. In response, certain master artisans assumed control of what was once a collective endeavor and gained access to the political sphere, a privilege previously denied to artisans.[5]
In the 16th century, Leon Battista Alberti wrote the De Re Aedificatoria, a treatise about the role of a new entity called the architect. It imposed an irreproachable respect to the intended design of the architect in the execution of buildings.[6] The new profession took authority over the artisans and the builders, by neglecting their capacity to create and to design.[7] Alberti stated:

"I should explain exactly whom I mean by an architect: for it is no carpenter that I would have you compare to the greatest exponents of other disciplines: the carpenter is but an instrument in the hands of the architect." [8]

Drawings became essential tools of abstraction representing the designer's authority, due to the formalization of the perspective.[9] Moreover, the printed and drawn codified directives for the work of stonecutters, carpenters, and masons by Desargues in the 16th century caused consternation among artisans, who felt that their abilities were being taken away from their control.[10]
As a result, not only were artisans detached from the design process, but architects were also distanced from the construction phase.
This marked the initiation of a pivotal cognitive shift, where the dominance of intellect over tangible materials has persisted in building practices until the present day.[11]

1. Cardoso, 2015, p.16
2. Reed, 2020, p.1
3. Cardoso, 2015, p.1
4. Cardoso, 2015, p.18
5. Cardoso, 2015, p.16
6. Witt, 2022, p.35
7. Cardoso, 2015, p.15
8. Witt, 2022, p.37
9. Cardoso, 2015, p.16
10. Cardoso, 2015, p.16
11. Cardoso, 2015, p.15

As stated by Daniel Cardos Larsch in *"Builders of the Vision: Software and the Imagination of Design":*

"emergence of a new social actor defined by a loss of the tactile link with materials enabled by design inscriptions; an exclusively visual relationship with buildings through drawings; and an increasingly complex social structure organizing their work."[12]

Notably, no substantial technological changes occurred in building techniques since the Medieval era, as matters were focused around new codification and representation means.[13] This can be attributed to the Renaissance's manufacturing approach, which heavily depended on reproducing forms from classical antiquity, employing construction methods that were largely similar to those of the ancient era.[14]

The Construction Company

In the 19th century, the Industrial Revolution, rapidly replaced artisanal methods with machinery, fueled by population growth and technological advancements and increase in efficiency.

Notable advancements in mass production and standardization emerged amid the economic surge and the influence of Taylorism and scientific management.[15]
With a demand for efficiency and rapidity in construction, some professions and other military-like organizations started claiming authority.[16] Large firms and contractors, with the adapted size and organizational structure, were equipped to oversee entire construction processes, challenging the advantageous relationship held between architects and patrons.[17]
Moreover, the demand for standardization necessitated drawings and documents of heightened precision, fundamentally altering the organizational dynamics of manufacturing and architecture firms. This transformation relegated architects and artisans to roles akin to ants in an ant-nest, confined to repetitive production and drafting tasks.

12. Cardoso, 2015, p.20
13. Carpo, 2017, p.35
14. Carpo, 2017, p.36
15. Cardoso, 2015, p.21
16. Cardoso, 2015, p.22
17. Cardoso, 2015, p.23

II. Waste

In contemporary industry, wood processing generates substantial amounts of waste. Stricts standards are limiting the utilization of imperfect wood, and processing contributes to increased waste through cutouts.

Cutout

In the course of wood processing, the material undergoes large waste cutouts, primarily influenced by the cutting patterns chosen by sawmill manufacturers and subsequent laminations for glulam production.

Norms

Sawmills lack the capability to process curved wood. In consequence, standardization has diminished the utilization of imperfect wood in the construction industry.

Sicknesses

Over time, the exploitation of monocultural softwood forests has proven to be more efficient in the mass production of wood, but it has had significant repercussions on the forest ecosystem by diminishing its capacity to regenerate.[18] In tandem with climate change, certain species like spruce, commonly used in construction, are experiencing heightened vulnerability. Pests such as the spruce bark beetle (bostrychl) are exacerbating their decline and gradually contributing to their disappearance.[19]

The industry largely converts most of the waste into biomass energy, asserting its carbon neutrality as it releases only the carbon previously absorbed by the tree during its growth.
IPCC guidelines of 2006 underline, however, that biomass energy is not 100% carbon neutral in all cases.[20, 21] Whether deemed neutral or not, the process releases CO2 that would have otherwise been stored if the waste were utilized in the production of construction elements.

III. Distance

Since the 19th and 20th centuries, the adoption of fossil fuel-powered machines and advancements in transportation has significantly increased the distances over which materials are transported.[22] In consequence, the industry produces large amounts of CO2 emissions. In 2023, Switzerland's emissions produced by the industry accounted for 30% of CO2 released by transports.[23]
Another repercussion is that when wood is transported beyond its original region, it becomes more susceptible to infections and infestations by insects it isn't used to.

18. Kola et al. 2021, p.2
19. Rts, 2023
20. Leturcq , 2018, p.3
21. IPCC, 2007
22. Schindler, 2009, p.138
23. OFEV, 2023

IV. Digression

Before diving into the proposed solution it is important to discuss the problem of the over-use of wood in contemporary industry.

Wood is Overrated

Nowadays, the advantages of wood for heat insulation, renewability and carbon storage makes it one of the most interesting construction materials for the industry.[24] It holds the potential to significantly reduce the carbon footprint of construction and is considered highly beneficial for various purposes.

Despite economic and ecological advantages, a material's promotion as a universal remedy can, however, have consequences on the larger scope.
In *"Thin Shells in a Thick Sea of Concrete"*,[25] Sarah Nichols outlines a similar narrative. Post-war concrete use, initially justified the wide spead use of the material through its optimization. Isler structures demonstrated economic efficiency in thickness-to-span ratio, seemingly positive for resource use.[26] Despite concerns about carbon emissions, the cement industry defended lightness and material economy, deflecting criticism to concrete brutalism, sustaining cement dominance.[27]

The core issue, however, lies in the global industrial implications, reliant on heavy systems in the building material supply chain.[28] Concrete's affordability and shell optimization during a post-war economic boom led to widespread use across Switzerland, resulting in a significant total material and carbon footprint. Compensatory measures and increased cement use followed reduced material usage, intensifying the environmental impact of this globalized concrete application.[29]

No material can be universally applied, as extensive usage of any material carries environmental and economic consequences, irrespective of its renewability. Additionally, each material possesses unique qualities, and its appropriate use depends on logical applications. While concrete is exceptionally reliable for heavy structural applications, its widespread use raises environmental concerns. Similarly, wood is versatile for various purposes, yet its utilization in large structures is resource-intensive, requiring the incorporation of iron and artificial additives. Its real ecological use thus relies on whether "they were predicated on heavier systems, both in terms of the building material supply chain but also in terms of the built environment more generally".[30]

24. Svilans et al. 2019, p.96
25. Nichols, 2023
26. Nichols, 2023, p.2
27. Nichols, 2023, p.11
28. Nichols, 2023, p.4
29. Nichols, 2023, p.5
30. Nichols, 2023, p.4

Proposal

The ascendancy of productivity concerns has marginalized the significance of architectural design as a central discipline. It is imperative to reinstate an appreciation for construction and reintegrate it into our professional endeavors. A crucial starting point involves comprehending manufacturing processes and acknowledging their environmental and social implications.

Construction is power. Thus, to elevate the quality and validity of labor, specific skills need to be trained again coupled with decision-making and autonomy: Empowering workers could enhance motivation, workflow and efficiency.[31]

Solution

The proposal is an on-site approach of wood conversion. It will combine advanced tooling and traditional hand tools to empower workers, architects, and reduce the limitations of today's industry.

On Site

Working directly in the exploitation area could help reduce long transports of wood logs. The complex working contexts will also promote adaptable human scaled approaches instead of large factory machines.

Hand Tool

Despite the limited transports and technology in the pre-industrial era, hand tools have permitted building monuments that still stand today. The flexibility of hand tools allows processing in all types of situations. The amount of waste is also minimalized, by following better the curves and imperfections of the natural material.

Hand, Machine and Information

However, since hand tool conversion is still a slow process, machines can be used in precise steps to augment efficiency. Nowadays, information about a given task can be integrated into the instrument.
Recognizing that humans may be less suited for repetitive and consistent execution of precision tasks, they can however better adapt to unexpected situations, respond to complex information, and make decisions accordingly.
Empowering workers through collaboration with robots can enhance motivation, workflow efficiency, and the overall processing capacity of robots.[32,33]

31. Parascho, 2022, p.191
32. Parascho, 2022, p.191
33. Dégallier-Rochat et al. 2022, p.4

Methodology

The study is divided into 3 chapters that represent the pre-industrial, the industrial and the post-industrial paradigm:

I. Hand
What happens when the Hand is introduced in Wood processing?
Waste, distance and skills in the pre-industrial era.

II. Machine and Hand
What happens when Machines are introduced in Wood processing?
Waste, distance and skills in the industrial era.

III. Information, Machine and Hand
What happens when Information is introduced in Wood processing?
Waste, distance and skills in the post-industrial era.

The two first chapters will follow the appearence and the use of tools in the historical context. Afterwards they will describe the process involved in representative projects. Visits to key actors' places were made during the study.

The reconstruction of Notre Dame through green wood squaring.
A visit to the forge of Serge Turberg in Malleray, Switzerland.
A visit to the "Atelier de la Grande Oye", Lods, France.

The construction of a 14-floor wooden tower in Malley, Switzerland.
A visit to the forestry rangers in Ropraz, Switzerland
A visit to the Sawmill "Scierie-Zahnd" in Ruyeres, Switzerland.
A visit to the JPF-Ducret factories in Orges and Yverdon, Switzerland.
A visit to the construction site of the tower Malley Phare, Switzerland

Finally the last chapter will give a proposed solution, drawing from examples of contemporary research in the field.

Importantly, the chronology chosen follows the one developed by Christoph Schindler in his publication:
"Ein architektonisches Periodisierungsmodell anhand fertigungstechnischer Kriterien, dargestellt am Beispiel des Holzbaus".[34]
He exposed the domination on wood making by hand tools followed by machine tools and information tools
He underlined, it is essential to understand that technological evolution shouldn't be seen as linear steps but rather as overlaps with socio-economic dominance hierarchies.

34. Schindler, 2009, p.87

Hand

Tools

Process

What happens when the Hand is introduced in Wood processing?

The chapter exposes how traditional green wood squaring has the potential to reduce the impacts of waste and travelled distance while restoring workers's skills.
The period examined will start in the Iron Age and end in the Industrial Revolution.
The research will draw on examples and texts about wood squaring in Medieval France. The country was one of the most impacted by the practice and it is still at stake today.

The *Tools* chapter will dive into the evolution of hand tools, drawing on historical description and discussion with tool-smith Serge Turberg.

The *Process* chapter will follow the processing involved in wood squaring, from log to carpentry through the use of hand tools. The case of the reconstruction of Notre Dame, will be studied, drawing on visits to the forge of Serge Turberg and the caprenters of the “Atelier de la Grande Oye”.

Green Wood

The use of hand tools is as old as humanity, marking the transition from hunter-gatherers to pastoralism. It started by the use of agriculture and construction.[35]
In wood making, tools were used for converting wood logs to usable timber. Green wood squaring was practiced from the beginning of wood making till the Industrial Revolution. The first application was focused in boat construction. Houses at the time were mostly built out of stones and sticks.

Wood squaring consisted of manufacturing a wood log with an ax right after the wood was felled. A section of wood is formed mainly of 4 layers, from the middle to the exterior: coeur, duramen, aubier, ecorce (heart, wood, sapwood, bark). When squaring wood, the log is kept in one piece, only carving out the sapwood and the bark.

Oak was the most used wood in France because of its resistance and its local availability. No drying or preconditioning of the material was done. Sometimes the carpenters would let the wood dry for 6 to 12 months, but working dry wood with an ax was nearly impossible because the flesh became as hard as stone. Green wood was however easily cleaved with an ax. Moreover, assembly of timber pieces was more easy because green wood was flexible. The frame was then assembled and as long as all the structural elements were consistent in their species and year of production, the whole structure wouldn't have challenging deformations. Assemblies would have small slits and beams would curl slightly. In consequence, the buildings were durable and lasted for centuries till today.

Despite norms guidance and most wood-making manuals of today, building a wood structure out of green wood is not only feasible but has intrinsic advantages for contemporary challenges. In fact, it involved many other practices like local sourcing, rentability of material and empowered workers.[36, 37]

35. Schindler, 2009, p.95
36. Grande Oye, 2023
37. Turberg, 2023a

Waste: Rentability of Material

The material was essential and was used for all purposes in the Middle Ages giving it the name of Wood Age. It created polycultural woodlands which had great varieties of species and ecosystems.[38] Thanks to the flexibility of the handheld ax, any kind of shaped trunk could be used, despite its curve and defects.[39] In consequence, naturally crooked wood was used in shipbuilding, prior to the 19th century. Trunks with curvatures were specifically selected, which resulted in higher rentability of trees. Trunks and branches are furthermore, much more resistant when used in the direction of growth. In consequence, before the 19th century, curved wood was more expensive than straight wood.[40]
The practice of wood squaring also reduced the cutout waste by using most of the log in one piece. The two internal parts were kept together.[41]

Distance: Localism

Before the 18-19th century, transport was very limited, and wood needed to be gathered from local forests, or at least squared before transport.[42]
A drawback of manufacturing green wood was its increased weight. To facilitate lighter transportation, wood was consistently cut during the winter season when it was drier.[43]
However, the hand tool's flexibility allowed it to be used anywhere. Consequently, green wood squaring was frequently carried out in forests or local areas.

Skills: Cupules

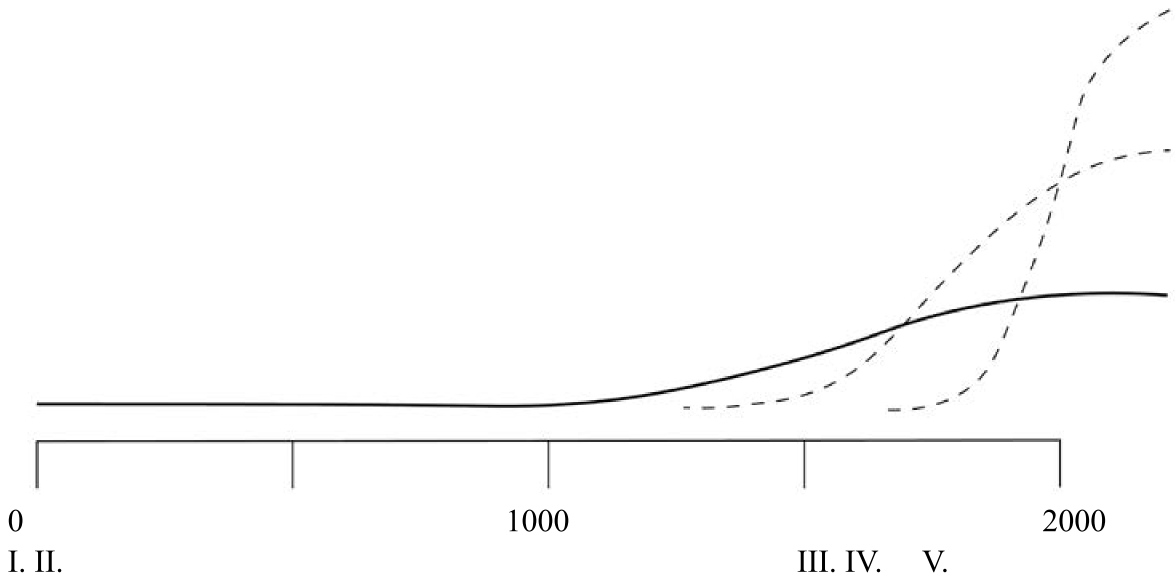
When wood was cleaved with an ax it generated consistent and repetitive marks known as "cupules". These served as the distinctive signatures of the carpenter, showcasing their skills and autonomy in crafting the final product.
Both the artisan's knowledge and the secrets of the woodlands were guarded within closed communities. This information was protected, decentralized, and communicated solely through oral traditions.[44] With the advent of sawmills and carpentry enterprises, the communities transformed into compagnonnage, functioning as a kind of syndicate that safeguarded the knowledge and autonomy of the workers.

38. Grewe, 2011
39. Grande Oye, 2023
40. Schindler, 2009, p.96
41. Turberg, 2023a
42. Grand Ouest de la France, 2011, p.41
43. Grande Oye, 2023
44. Cardoso, 2015, p.18

Hand

Tools

45.



I. Ax
II. Joint Tools
III. Single-Bevel Ax
IV. Saw
V. Machine hand tools

The following chapter will explore the evolution of hand tools throughout history and their implications on the environment and socio-economic context. The study is based on historical texts and discussions with toolsmith Serge Turberg.

A tool can be defined as a device held by the human hand to work on a material. Instruments not held, such as anvils, tables, and socles, are not considered tools. Hand tools for wood can be broadly categorized into two types: cleaving and cutting tools.[46]

Cleaving tools involve forceful striking along a line. When the edge reaches into the wood, the fibers are split and the dissolved chip is not removed from the wood, but used to guide the next strike. In consequence, the cutout side is unpredictable and turns into large chips. Cutting tools entail controlled scraping in an up-and-down motion. The cutout shape can be chosen precisely, but the chips are turned to dust and their dimensions can't be anticipated.

45. Adapted from graph, Schindler,2009,p.88
46. Duvauchelle, 1990, p. 5

I. **Ax**

The use of the ax lasted mainly from the 4th to the 15th century as the only wood conversion tool.

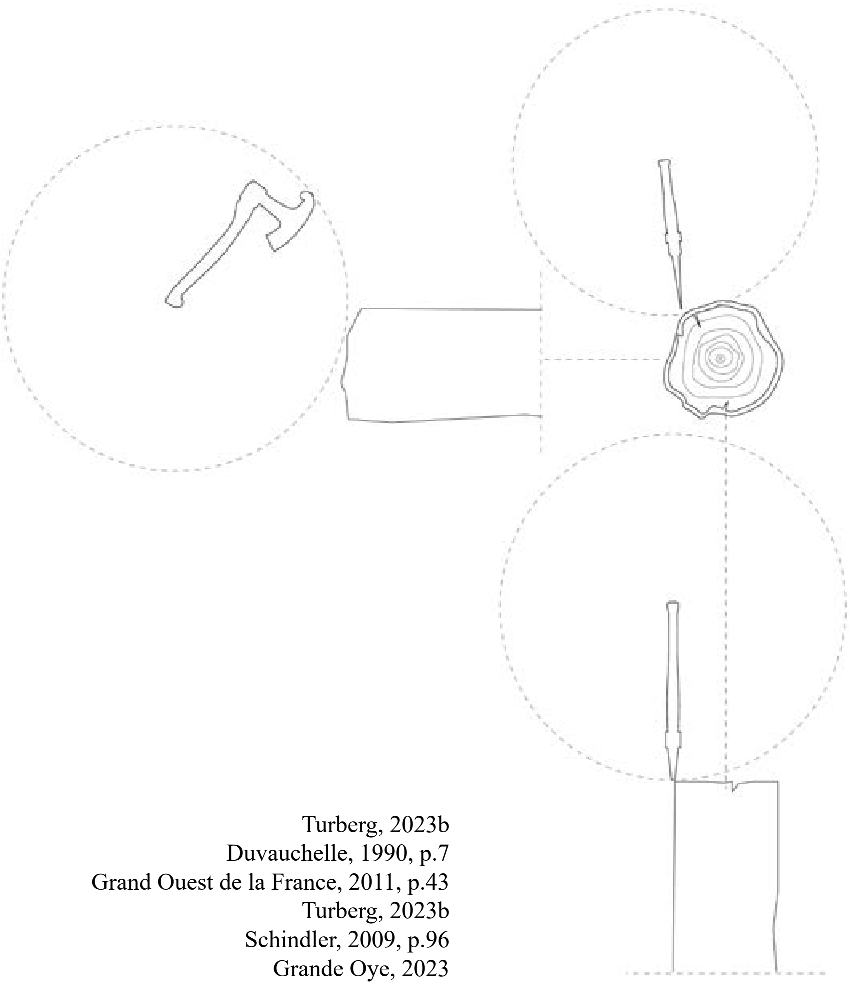
Bas-Fourneaux

First crafted tools can be traced in the Iron Age from 800 to 400 BC.[47] Forging was done in small ovens referred to as “bas-fourneaux”. Artisans would heat up iron ores, to 1400C°, together to form wedges, blades and tools. The result was a soft and malleable metal which was sharpened by the introduction of carbon on the surface by a process called cementation.[48]

The Ax

The first tool used for woodworking was a cleaving tool: the ax. It was an iron wedge attached to a wood rod. The limited size and the heating capacity of the oven didn’t allow yet turning iron into steel and making very sharp, large, strong tools. Additional woodworking tools, such as the herminette and the plane, did emerge, but their usage was infrequent and confined to highly specific tasks.[49] The production of iron did not evolve much from the Iron Age to the 15th century. All axes were crafted with a double bevel, featuring an angle of 30°, and their size remained consistent throughout the entire period.[50] Squaring from finishing were done as a result with the same ax. They were held with two hands, the dominant hand on the back of the shaft to guide the cut and the other hand near the wedge to hold the weight.[51] An artisan could square up to two logs in a single day.[52]

The following drawing shows the different angles of attack of the ax (front, side, top)



47. Turberg, 2023b
48. Duvauchelle, 1990, p.7
49. Grand Ouest de la France, 2011, p.43
50. Turberg, 2023b
51. Schindler, 2009, p.96
52. Grande Oye, 2023

La Poulaine

A few years ago, Serge Turberg, the toolsmith responsible for the reconstruction of Notre Dame, discovered the last known double-bevel ax from the 13th century called the Poulaine. *(n°1 page 21)*
He designated 3 topological points on the blade: the brise-fil *(n°1 page 22)* is in the third part of the bottom of the blade. It is the section initially employed to penetrate the wood. Then, the bride-noeud *(n°2 page 22 middle)* is the lowest corner of the blade. It is the least sharp part, used only for breaking nods of the wood. Lastly, the poulaine, from which the ax derives its name, refers to the highest corner of the blade. It was utilized for clearing wood chips from the surface of squared wood and symbolically represented the front of a ship.
Despite differences in geography and time, other axes exhibited similar dimensions. Only the symbolic significance of each topological point underwent alterations.
The ax described by Viollet-Le-Duc for medieval France, had a symmetrical triangulated blade. The ax of Harald blue-tooth, the king of Denmark which had a brise-noeud made into water waves and a poulaine made into the front of a Drakkar.[53] *(n°2 page 21)*

Anywhere

The advantage of axes and hand tools, in general, lies in their versatility for use in various locations. Since the inception of woodworking, especially during the limited transport capabilities of the Middle Ages, wood squaring had to be carried out on-site or in the forest.[54]

Any wood

Axes possess the capability to split logs of any size and shape. When the wedge of the axe is not overly large, it can skillfully follow the curve of a crooked tree, accommodating a diverse range of wood. Furthermore, squaring hardwood with an axe is easily achievable, as the flesh of the wood tenderizes during the cleaving process when it is still green.

Fibers

Vikings boat makers understood that cleaving tools made timber with higher strength and less breaking tendency.[55] Axes split fibers in their direction, tightly cleaving the flesh and rendering the surface waterproof. That’s why wood squaring was first used for ships in the Middle-Ages. It is less the case with single-bevel axes because their large and thin blade follows less the fibers. The same goes for saws, in consequence, the fibers are torn open, resulting in more delignification. With the increase in delignification. the resistance of the timber decreases.[56]

This elucidates the prolonged dominance of axes in woodworking, spanning from the iron age to the industrial era.

The five following pictures are historical axes reproduced by Serge Turberg

53. Turberg, 2023b
54. Grande Oye, 2023
55. Larsen, 2022, p.495
56. Schindler, 2009, p.108


LA POULAINE hache d'équarrissage
Cette hache a été développée par Serge Turberg forgeron taillandier à Malleray. Elle est le fruit des recherches menées sur l'outillage des charpentiers du 13ème siècle et plus spécialement étudié pour la taille de la nouvelle charpente de la cathédrale Notre-Dame de Paris. Sa géométrie se base en partie sur les modèles de hache viking spécialistes équarrisseurs dans la construction de navire (drakkar).
Le nom poulaine est issu de la partie avant de certains bateaux, dont la forme recourbé rejoint la géométrie de l'outil. Ce modèle fût probablement utilisé par les moines bâtisseurs bénédictins régis par la règle de St-Benoît et plus spécialement lors de la construction de l'abbaye de Cluny III.

II. Joint tools

Before the 19th century, squared timbers were assembled in different types of wood-wood joints: mortise and tenons, finger joints, lap joints, grooves and dowels *(page 26 from top to bottom).* Numerous joint variants exist, including butt joints, dovetail joints, corner joints, plate joints, comb joints, offset joints, and claw joints. Each type has numerous variations that vary depending on the specific situation. The construction site and carpenter's technique contribute to different results. In Japanese joinery alone, there are at least 1000 variants.[57]

Chisels

Creating intricate connections with an axe was challenging due to its size and the limited movements. However, with the advent of bas-fourneaux in the Iron Age, smaller joint-making tools were invented. Chisels emerged during the Iron Age as a compact cleaving tool, enabling the creation of smaller wood joints. Consisting of a small iron blade shaped like a tooth attached to a wooden stick, the chisel was held with one hand while the other hand struck it with a hammer. The compact size of the tool allowed for the foring of single bevels, a feat impossible with axes during that period. This tool was employed for carving holes and notches in wood.

The hand flexibility allowed for the creation of curved cavity joints, absorbing the deformation of the green wood. For instance, oak wood looses 2cm every year by drying. Presumably, the carpenter anticipated the final dimension of the wood at the time of construction.[58]

57. Schindler, 2009, p.96
58. Grande Oye, 2023

La Bédane

The "Bédane" was a chisel with a blade thicker than it was wide, featuring a single bevel, was utilized to create deep mortises with vertical flat surfaces. The front of the blade was narrower to prevent it from getting stuck in the hole.[59] *(n°1 page 25)*

Le Fermoir

It resembled a "Bédane" but had a blade that was wider than it was thick. This tool was employed to create shallower mortise holes.[60] *(n°2 page 25)*

La Gouge

A chisel that had a bevel with a round or a v shape, used to create notches and moldings.[61] *(n°3 page 25)*

Le Ciseaux Droits

A chisel that had a wide straight bevel on the tip. The width of the bevel varied in relation to the thickness of the notch.[62] *(n°4 page 25)*

La Bisaiguë

A lengthy tool bar with a central handle, featuring a straight chisel on one side and a "Bédane" on the other. The carpenter held it with both hands and pushes it through the wood to carve out tenons or mortises.[63] *(n°5 page 25)*

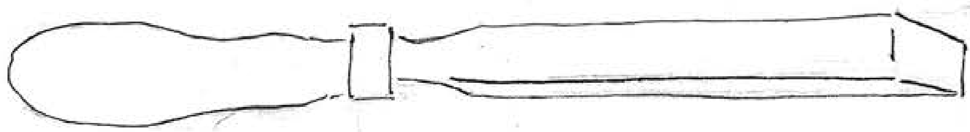
La Tarière à vis

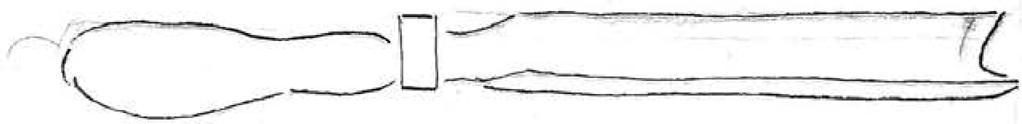
In the 15th century, iron drills were invented, aiding in the creation of circular long holes for dowel joints. One example is the "La Tarière à vis," an iron drill inserted into a perpendicular wooden handle. Carpenters operated it by turning the handle with both hands, allowing them to drill through the wood.[64] *(n°6 page 25)*

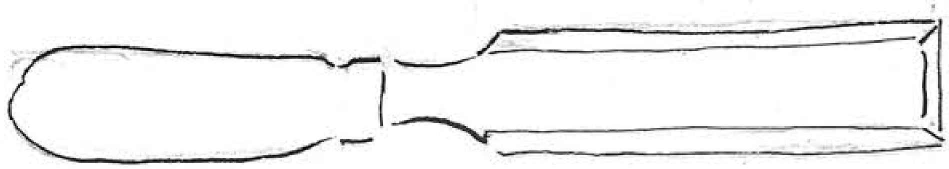
Jigs and Templates

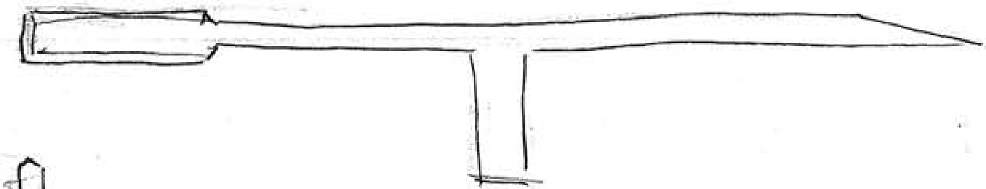
In cases of mass reproduction, such as the construction of large monuments, it is conceivable that carpenters utilized jigs and templates to ensure the consistent replication of joints.

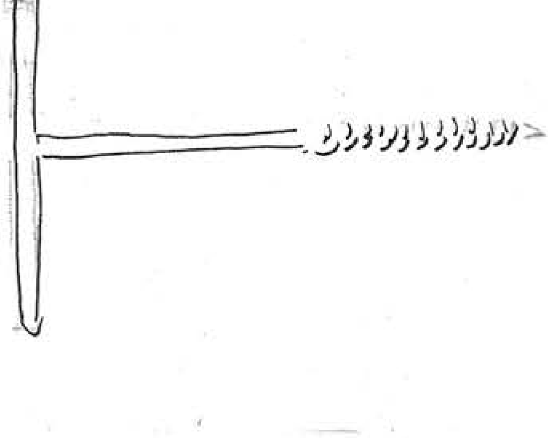
59-62. Duvauchelle, 1990. p.22-23
63. Grand Ouest de la France, 2011, p.81
64. Calame, 1993

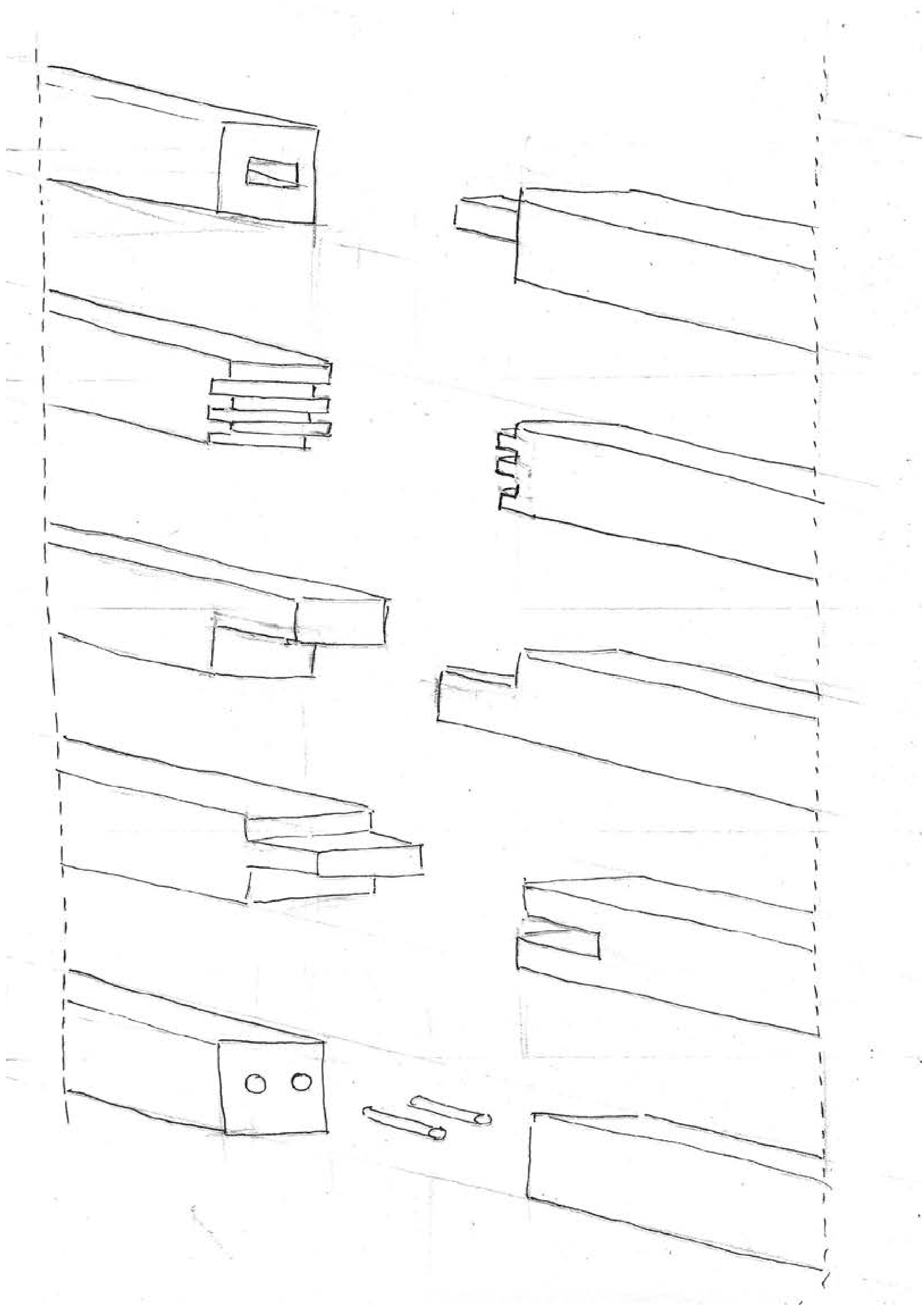












III. Single-bevel Ax

From the 15th to the 20th century, advancements in iron-making technology allowed for the production of thinner, stronger, and larger tools.

Haut-Fourneaux

With the increasing demand for iron, large ovens called haut-fourneaux were developed in the 15th century, capable of reaching the melting temperature of iron. The higher temperature, in close contact with charcoal, led to the creation of a new alloy between iron and carbon known as steel. As a result, it became possible to shape the material in any form and make it harder than ever before.

Doloire

The large ovens played a crucial role in producing larger and thinner blades, such as single-bevel blades. Carpenters, for instance, utilized a new type of axe called "la Doloire." The new type of ax was mostly used for finishing and enabled the creation of more consistent and flat surfaces.

Bratva, Breitbeil

These axes resemble the ones used in recent wood squaring practices, such as those employed in the "Atelier de la Grande Oye." They share similar dimensions with the "Doloire", where one is utilized for squaring the wood, and the other is employed for creating the finishing surface.

Longue-jambe

In his archaeological research, Serge Turberg discovered a 15th-century axe known as "la Longue-Jambe." This axe featured a large wedge with a double bevel and was designed for wood squaring, allowing craftsmen to avoid hitting their hands on the wood while working with large sections. The large and heavy head of the axe facilitated a more straightforward cutting movement.

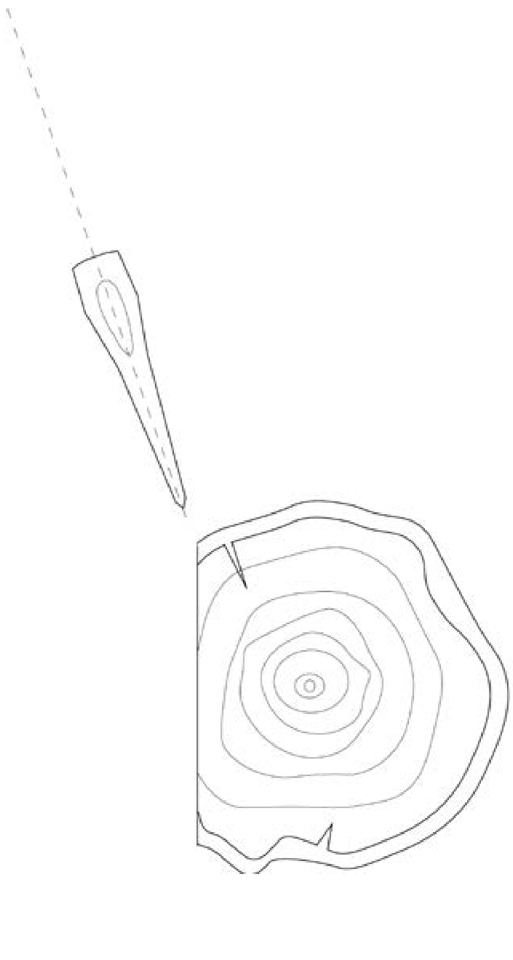
Double-Bevel vs Single-Bevel

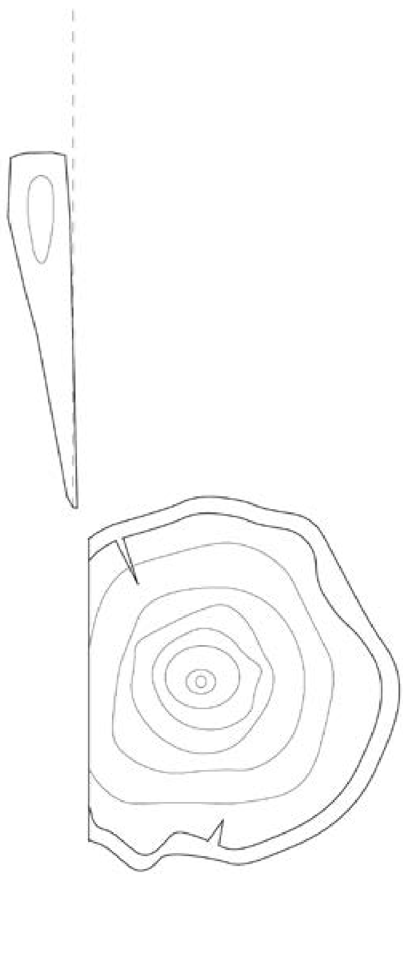
(bottom page 28)
The distinction between squaring and finishing tools facilitated a prolonged and uniform drawing on the wood's surface. While the "Cupule" yielded a cleaner result, it retained subtle irregularities inherent to both the wood fibers and the individual carpenter's style.

Unlike a double-bevel axe that completely severs fibers, the single-bevel flattened them, resulting in a surface less impervious to water. Moreover, when employed for cleaving, the single-bevel axe easily penetrated beyond the cutting line. This limited the carpenter to working in only one direction along the trunk, requiring the wood to be squared from the bottom to the top to avoid encroaching on the sapwood due to the cone-like growth pattern of tree trunks.

Lastly, the use of larger wedges offered reduced flexibility compared to smaller axes, and curved logs presented challenges, limiting their usability in carpentry.[65]

65. Turberg, 2023b





IV. Saw

Despite former prototypes in the Iron Age, the wide use of saws only appeared with the large ovens in the 15th century.

Turberg theorizes that the earliest saws could have originated from repurposed swords with damaged blades resulting from combat. The inaugural crafted saw took the form of an elongated and thin iron blade equipped with teeth, accompanied by one or two wooden handles. The cutting action involved a pull-push motion, and to maintain blade integrity, a tension frame was commonly employed above.

Forge Limitations

The advent of saws is thought to have coincided with the emergence of small ovens. However, the forge's capacity did not allow for the creation of large and thin elements, and the iron produced was not sufficiently hard to craft saws without tension. The challenge of making saws without steel further compounded the difficulty.
This difficulty in crafting saws likely rendered their practicality questionable until forging technology could advance. The same challenges applied to the production of sawmills. The invention of haut-fourneaux marked a turning point, enabling the creation of blades that were long, thin, and comprised of hard steel. Consequently, saws could be manufactured without the need for tension frames.

La Scie à Refendre

The iron blade was held in tension with a frame made out of wood or iron. A first example was “La scie à archet” in the shape of an arch. Similarly, “La scie à refendre” was set on a rectangular frame and the horizontal post served as a handle and the blade was put in tension with a rope. It was the most widespread saw giving it the name of “Scie Universelle”.[67] *(n°1-2 page 30)*

La Scie de Scieur de Long

Similar to its predecessor, the blade of this saw was positioned at the center and perpendicular to the frame. This configuration allowed for the cutting of a trunk along its length, with the assistance of two carpenters—one positioned above and the other below.[68] *(n°3 page 30)*

Le Passe-Partout

A long and large blade without a frame with one handle on each side. Also operated by two carpenters, it was used to fell trees. Other variants like la scie à guichet and la scie égoine have only one handle with a blade in the shape of a long triangle.[69] *(n°4-5 page 30)*

66. Schindler, 2009, p.96
67-69. Duvauchelle, 1990. p.18-19

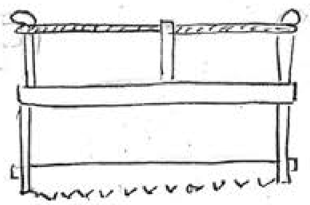
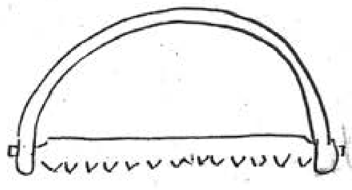
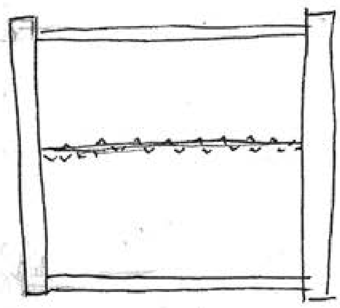
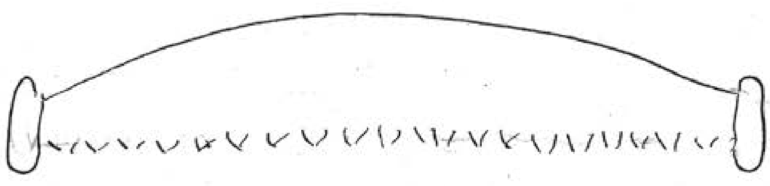
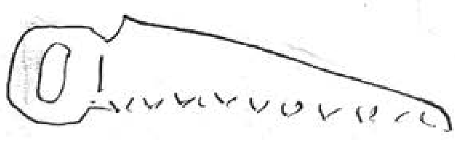
Ax Dominance

Large-scale boat fabrications in Denmark around the 13th century were done entirely with axes which shows the prominent use of the tool.[72] They demanded less effort.[73] Furthermore, saws and sawmills were unable to effectively cut curved logs compared to axes.
Axes were dominant in hand woodworking till the end of the Middle Age and saws were used punctually to correct the length of an already squared wood and to make joints.[70, 71]
Moreover, because saws do not cleave but rather cut through the wood, the fibers are torn, rendering the surface vulnerable to water damage. Additionally, the wood chips produced by saws are smaller than those generated by axes, leading to heightened delignification and a reduction in the overall resistance of the wood.

Sawmill Dominance

The introduction of sawmills in wood manufacturing marked a shift, causing axes to gradually lose their dominance. This transition will be further explored in the upcoming chapter dedicated to "Machine and Hand" methods.

70. Grand Ouest de la France, 2011, p.43
71. Calame, 1993
72. Turberg, 2023b
73. Schindler, 2009, p.96

V. Hand machine tools

Hand-held machines emerged in the 19th century and have seen limited evolution since then. These tools were designed to aid in woodwork by employing machine-driven motion. Their utility extended to simplifying intricate processes in wood squaring, such as handling large sections and creating complicated joints.

However, their role and significance in the history of wood construction are somewhat anecdotal, given the overwhelming dominance of sawmilled wood. Furthermore, the invention of hand-held machines came later than that of machine-powered sawmills, as it required a portable and lightweight power source.

These hand machines were powered by gasoline or electricity depending on the specific application and requirements.

Hand Drill

In the 19th century, the first handheld machine tool with an integrated power engine emerged. This device featured a steel drill positioned at the machine's tip, rotating at high speed to create cylindrical holes. Its initial application greatly facilitated the production of dowel joints. However, as time progressed, its use shifted towards the creation of screw holes. Notably, the hand drill evolved to be powered by electricity, marking a significant advancement in its efficiency and versatility.[74] *(n°1 page 32)*

Jig Saw

In the 20th century, a notable development occurred as a small saw was integrated into a hand machine, enabling a repetitive cutting motion. This innovative tool was designed for precision, allowing the cutting of thin planks in both length and width.[75] *(n°2 page 32)*

Chainsaw

The chainsaw featured a chain curled around a blade, operating at high velocity. Initially powered by gasoline, it was primarily employed in forest environments for tree felling, earning its initial designation as the "tree-felling machine." Beyond its primary function, this tool played a crucial role in streamlining the initial stages of wood squaring, including the cutting of larger sections. However, for a refined surface finish, the ax remained indispensable and continued to be utilized alongside the chainsaw.[76] *(n°3 page 32)*

Mortise Machine

Various iterations of hand drills and jig saws have been developed to enable the creation of specific holes for wood joints. Specialized tools, such as mortise machines, play a key role in effortlessly producing consistent square holes. These advancements in woodworking equipment contribute to the precision and efficiency of crafting joints in woodwork. *(n°4 page 32)*

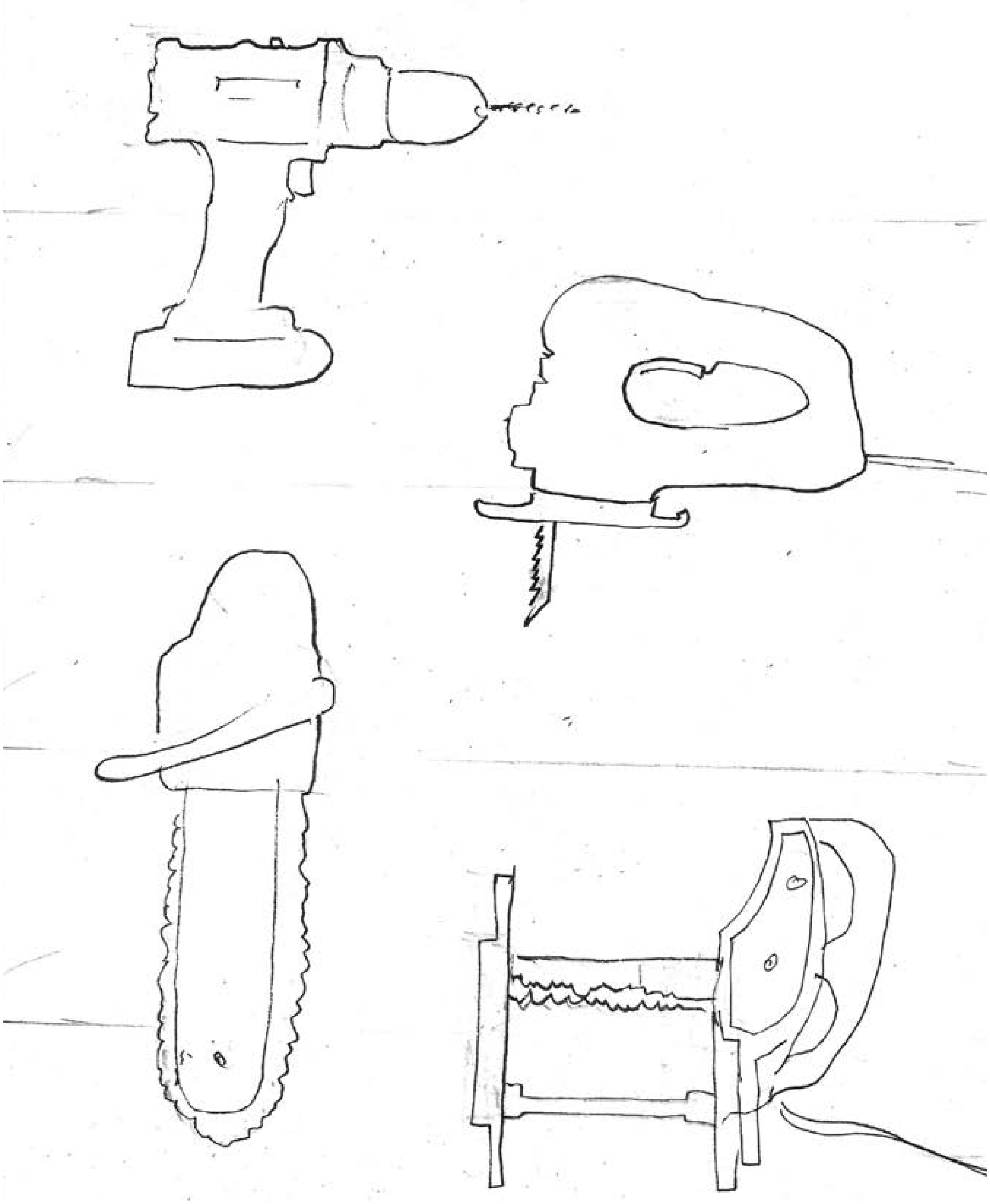
74-76. Schindler, 2009, p.101

Adapted applications

The "Atelier de la Grande Oye" provides a compelling example advocating for the use of machine tools in specific aspects of wood squaring. Tasks like crafting tenons and mortises, traditionally laborious for carpenters, are expedited through machine assistance, ultimately saving time. This approach was notably employed in the reconstruction of Notre Dame, where large oak sections for beams underwent initial machine sawing to enhance efficiency.

Despite the initial machine work, purists may raise concerns; however, all surface finishing and joint detailing are meticulously refined with traditional tools such as axes and chisels. Mortise holes are redefined with a chisel to incorporate some cavity, a crucial element for absorbing the framework's potential deformation.

In summary, machines offer increased productivity while allowing space for human craft and enhancements. This harmonious integration of technology and traditional skills reflects a balanced approach in woodworking practices.



Conclusion

The historical evolution of woodworking tools, particularly the ax, underscores the relation between technological advancements and the preservation of artisanal works. From its early use in squaring wood for boat construction to the construction of monuments, the ax has been a constant companion in shaping the built environment.

Waste

One remarkable aspect of the hand tool's period is its role in leveraging the unique properties of curved wood. The flexibility of the ax, allowed carpenters to work with shaped trunks, embracing their curves and defects. This not only facilitated the utilization of a diverse range of wood, but also contributed to the establishment of polycultural woodlands with varied species and ecosystems.

Transportation

The practice of wood squaring reduced the need for excessive transportation. In an era where transport was limited and wood had to be sourced locally, the hand-held ax made it feasible to work with green wood directly on site.

Skills

Hand tools harnessed the skills of the carpenter, providing flexibility and adaptability that influenced the two challenges mentioned above.
In the contemporary era, machine tools like the chainsaw, hand drill, jig saw, and mortise machine have further improved efficiency in wood squaring, especially for complex tasks. Traditional hand tools, such as the ax and chisel, nevertheless, remained indispensable for finishing work, proving the utility of carpenters' hand skills.

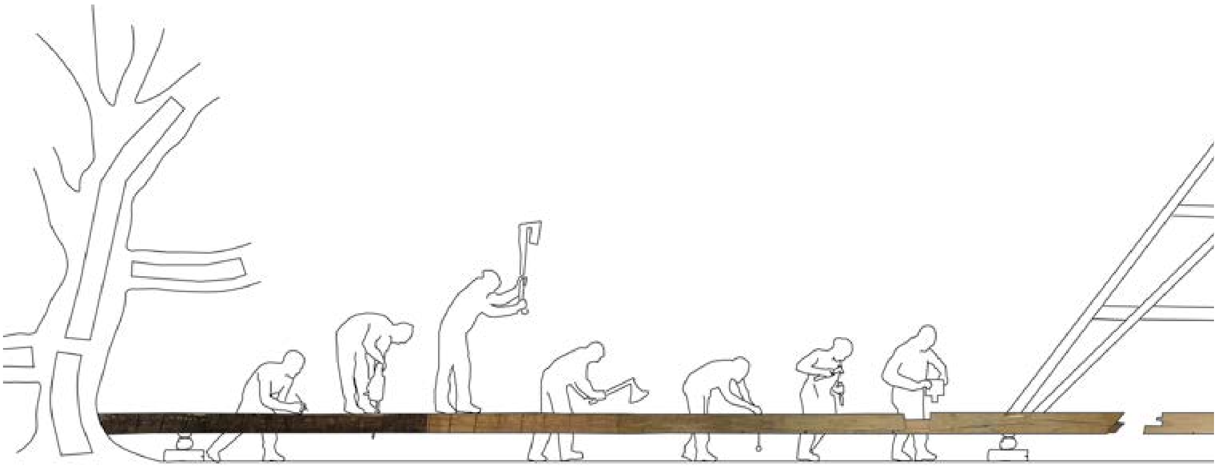
Despite the appearance of saws and machines in pre-industrial times, axes remained dominant for wood conversion. Cleaving gave timber structural and resilience advantages over other tools. The ability of hand tools to work with curved wood reduced waste and transportation needs in historical contexts, which resonates with sustainable woodworking practices of today. As we reflect on the evolution of woodworking tools, it becomes clear that the adaptability and flexibility of hand tools have not only shaped our heritage but also contributed to a more harmonious relationship with nature and its resources.

The subsequent chapter will delve into the resurgence of contemporary applications for hand tools.

	Forge	Tool	Axes
-500	bas-fourneaux	Ax	
		Chisel	
0			
500			
			Harald Ier
1000			La Poulaine
			Viollet-Le-Duc
	haut-fourneaux	Single-bevel	
1500		Wide axes	Longue-Jambe
		Saw	Doloire
		Drill	
2000		Machine Drill	Breitbeil
		Chainsaw	Breitva
		Jig Saw	

Hand

Process



I. Selection

II. Squaring

- A. Tracing
- B. Nicking
- C. Smashing
- D. Finishing

III. “Épure”

- A. Tracing
- B. Mise sur ligne
- C. Joint
- D. Assembling

IV. Construction

The upcoming process chapter will center around the reconstructing the frame roof of the Notre Dame Cathedral, showcasing a rebirth of green wood squaring on a grand scale. The process will feature visits to representative enterprises, providing in-depth explanations of the various steps.

A visit to Serge Turberg’s forge offered insights into the tools and historical research driving the Notre Dame roof frame reconstruction.
A visit to the "Atelier de la Grande Oye" explored the practical steps involved, spanning from the careful selection of trunks to the final frame construction.

Rebirth

"In 1968, I was eight years old, and I spent all my time in the forest with a lumberjack who needed me, not to cut wood, but to maintain his campfire. It was the first time in my life that I saw a chainsaw. The machine was introduced in Switzerland in the 1960s. He would cut a tree with the chainsaw. And when he was done, the machine was so heavy, so big. He hesitated and said: What do I do, do I take the ax or do I take the chainsaw? Then he would say: Ah! I'll take the ax. He would turn his shirt, and all day you would hear: Chlaa!...Chlaa!...Chlaa!... He was removing the branches with the ax." [77]

Serge Turberg's lifelong fascination with historical tools and practices led him to specialize in artisanal cleaving tool making and artistic iron making for fourty years. Operating from his forge in Malleray, Switzerland, Turberg graciously shared his expertise during an interview where he answered my questions.

Several years ago, François Calame, an ethnologist and founder of the "Charpentier sans Frontière", approached Turberg. Calame invited him to join the reconstruction efforts for Notre Dame, which had tragically burned down in 2019. The unique aspect of this project was the commitment to converting wood logs into timber structures solely using axes and hand tools—an approach Turberg was well-versed in due to his experience working with lumberjacks.

However, the reconstruction committee, comprised of architects, historians, and politicians, initially hesitated to embrace this historicist approach. Modern alternatives were favored, and skepticism surrounded the traditional wood squaring method employed by the artisans. The artisans found themselves having to repeatedly prove and justify the viability of their approach.

Firstly, the Office National Des Forêts (ONF) declined to deliver the required 1,300 oak trees due to concerns about deforestation. Interestingly, this quantity represented only a fraction (1/10th) of the French oak exportation to China. Nevertheless, private forest owners stepped in, generously donating a significant number of the required oak trees, effectively demonstrating that the demanded quantity was not as unreachable as initially perceived.

Subsequently, when the carpenters demonstrated their ability to square wood in the ancient methods, the commission raised concerns about the surface finish not matching historical standards. It was noted that the axes used in the 13th century differed from those in the reconstruction efforts. Consequently, Serge Turberg was commissioned to reproduce the historical ax. Conducting thorough research based on historical sources, archaeology, and descriptions, he successfully recrafted the ax known as "la Poulaine."

With the introduction of the historically accurate ax, the reconstruction efforts resumed without further obstacles.

77. Turberg, 2023b

Rebuild

"*When I was an apprentice, old timber frameworks, was all that interested me . I had the chance to visit old timber frames and wondered how they did that back in the day with their means? Where I was learning, they didn't really answer that, so I looked for myself, bought axes, inquired, and called François Calame and talked to two or three specialists about it. And then at some point, I got fed up with being an employee because the human atmosphere weighed too much on me. So, when I was young, I thought, I'll go freelance and do the work by hand. If it doesn't work, just too bad, I'll do something else.*" [78]

Paul Zahnd's enduring fascination with historical wood structures in France led him to teach himself the art of green wood squaring, becoming one of the few artisans to practice it professionally. Later, he joined forces with Julien Hentzy in the "Atelier de la Grande Oye," where they graciously shared their insights during my interview. Their commitment to green wood squaring sparked a movement, with around 50 carpenters embracing this traditional craft.

The "Atelier" expanded its scope beyond renovations to include the construction of new buildings, showcasing a growing popularity despite being labor-intensive. They strategically remained relevant by minimizing transport and machine costs, while also incorporating curved wood into their projects. Situated in a valley surrounded by woodlands, they sourced the majority of their materials within a 5 km radius, emphasizing sustainable practices.

The reconstruction of the Cathedral framework was entrusted to "Atelier Desmonts" in Eure and "Atelier Perrault." The "Atelier de la Grande Oye" produced 12 of the 46 secondary frames. This project not only aimed to restore the cathderale but also provided overdue recognition for artisanal carpenters like Paul Zahnd. Accepting the responsibility, they insisted on working in their own "Atelier de la Grande Oye" with their dedicated team of 4-5 people.

For their part, the reconstruction committee selected oak woods from Alsace. Upon arrival at the "Atelier," the wood logs underwent meticulous sorting and preparation, with green wood squaring performed using traditional axes. Larger sections were, however, partly cut with a chainsaw due to the difficulty to work it fully by hand. The cleaved wood was laid out on the floor according to a 1-to-1 scale drawing called "Épure." Joints were carefully drawn and cut, and the framework was pre-assembled.

Finally, the timber produced by various "Ateliers" was assembled at "Atelier Desmonts" to ensure correct coordination before being transported to Paris.

78. Grande Oye, 2023

I. Selection

Most of the wood used comes from oak trees thanks to its great resilience to water, deseases, insects and structural strength. Oak wood is ranked 3 on 5 resistant classes following the French norm NF EN 335-1 to 3[79], which means it is nearly indestructible.

As mentioned before, a section of wood is formed mainly of 4 layers, from the middle to the exterior: the heart, wood, sapwood and skin. When squaring wood, it is essential to remove the skin as quickly as possible, because it can contain sickness and insects that appear after the tree is felled.[80] The faster the tree is squared after felling, when it's still green, the more healthy it will be. To avoid storing the material for extended periods of time, wood is therefore selected with ang anticipated use in mind. When a carpenter chooses a tree, the precise use of the log is already set. The felling of the trunk won't be discussed as it is not done by the carpenters.

Defects

The flexibility of the hand tool, specifically the small wedged ax, permits converting logs of any shape despite its curves and defects. A log would be preferably curved only in one plan, so that it's possible to make the framework in a single plan. Industrial sawmills don't have the capacity to do so and curved woods are, therefore, used for energy. As a consequence, artisans can use cheaper wood and reduce waste.

Trees can also be used according to their natural growth and structural logic. The carpenter not only chooses a branch for its section size but can also decide where to use it in the structure based on its growing direction. The framework, therefore, can have structural advantages. If the axis of a structure follows the central axis of the log, fewer fibers are removed and the element is more stable.[81]

The wood has preferably not too many nods because they are difficult to square. Also, a structure containing many defects is less resistant and might break at the nod points. The appearance of more nods on the wood is the result of bad forest management. Trees are often grown too quickly and in uncompetitive areas resulting in degradation of woodlands.[82]

Seasonally

Depending on the season, one can choose a standing tree or an already felled tree next to the road. The trees are usually selected in winter, when all the sap has left down the tree. The log is also consequently lighter and less prone to infections as a consequence. The carpenters have to predict the wood they will need the whole year.

79. Point P, 2023
80. Turberg, 2023a
81. Schindler, 2009, p.107
82. Grand Ouest de la France, 2011, p.41

Locally

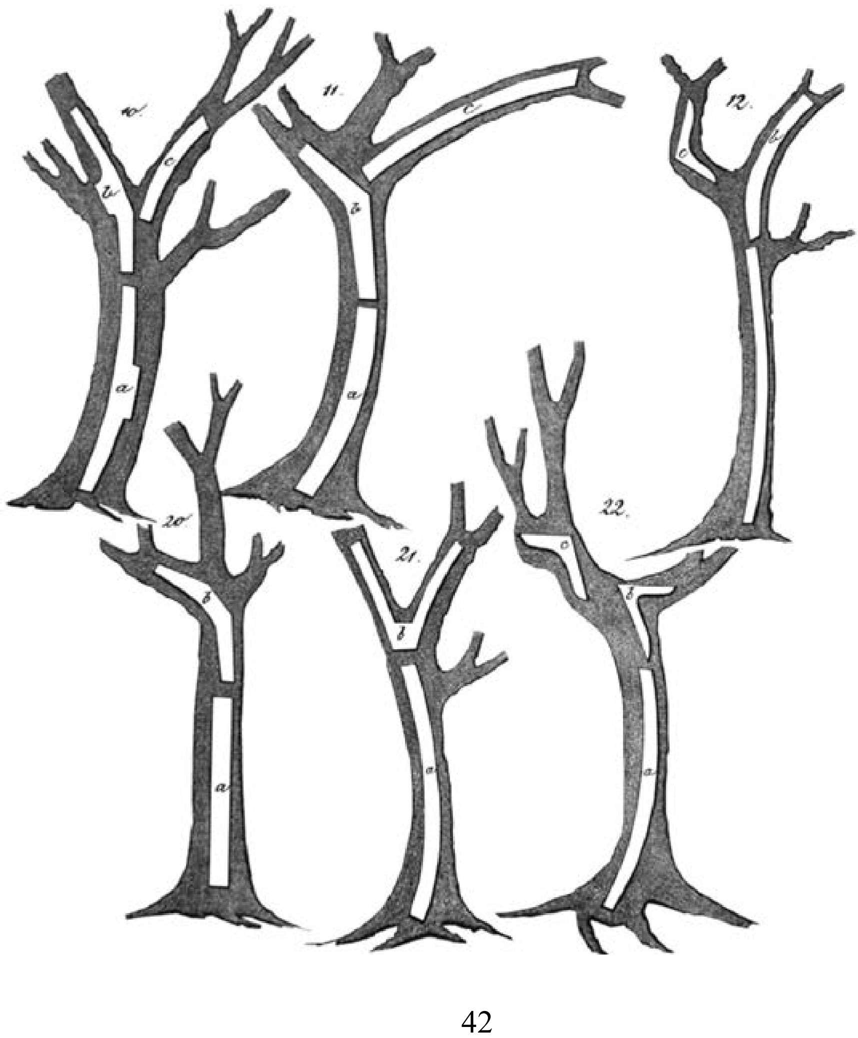
The transport is a bigger issue for sawmills than for axes. Since, wood squaring can be performed anywhere, it could be even in the forest itself. The carpenters of “La Grande Oye”, however, have a workshop, for practical reasons, where the log truck brings the wood. Usually, the carpenters harvest in forests that are situated within a radius of 5 km.

In the case of Notre Dame, the trees were brought from Alsace, which is around 250 km away. The wood was chosen by the reconstruction committee, for their beauty and quality. It was one of the highest quality and the most beautiful wood one could find. Upon arriving on site, as the carpenters started squaring, they, however, unrealized that the log was full of xylophagous insects.

Those high quality wood had, in fact, grown in the best conditions possible but grew too fast in consequence. The lack of species competition made the wood weaker to infections and due to the change of place and the time of transport, the supposedly indestructible oak was completely infected.

In opposition, the oak they extracted from local forest grows in the worst areas, on stoned ground and with difficult climate conditions. The wood is not as beautiful, but it is structurally stronger and more resistant to water and infections.
The experience of Notre Dame taught them that it is crucial to work with local wood to avoid transport and condition changes.

83. Image taken from Schindler, 2009, p.104



II. Squaring

The objective is to turn the round log into a square section. In the first step, two surfaces are flattened on the side of the trunk. Then the log is turned and the two last surfaces are done. A log has a sapwood with a thickness of 2-4 cm. It’s not structurally needed and it has to be removed to avoid diseases. Squaring the wood permits removing most of it.
This step is usually done after the winter season when all the logs have been selected and felled.

A. Tracing

The felled log is laid horizontally on two small wooden benches and fixed by an iron L bar called Clamot. The carpenter draws on each face of the log the desired and optimized section. The carpenters make sure the lines are horizontal and vertical with a level and plumb line. Then two parallel lines are traced on the bark connecting the desired sections. If the log is straight a chalked line called Cordex is traced. If the log is curved, the carpenter does the line by hand.

B. Nicking

The artisan stands on the log. A double-bevel ax is held in hands and hung vertically against the side of the trunk. Every 20cm the ax makes perpendicular notches reaching close to the desired line. Both sides of the laying log are flattened in that matter.

C. Smashing

The artisan still stands on the log and smashes away the notched sides with the same ax.

D. Finishing

The carpenter then takes a single-bevel ax and cleaves the surface of the wood. There is two possible working positions:
In line, one sits on the log and cleaves while moving forward.
Parallel, one stands next to the log and cleaves while moving forward.
When the two starting surfaces are done, the log is turned and the process is repeated.
In the case of Notre Dame, the beams were squared and finished with a single ax called La Poulaine. It’s a reproduction of a 13th century ax made by Serge Turberg.

Machines

For quicker results, the“Atelier de la Grande Oye” shows an alternative technique using a chainsaw instead of the ax. This step, in fact doesn’t have an influence on the finished result and is not peculiarly interesting for the carpenter.
In Notre Dame, the logs sections were unrealistically large for hand wood squaring. They decided to cut the two starting surfaces with a saw leaving an offset of 30mm. The offset was then cleaved with the single-bevel ax They again tolerated the introduction of machines but kept the finishing by hand.

III. “Épure”

“L’Épure” is a one to one drawing of the desired framework. All the timber elements are aligned on top for corrections, joints and assemblage.
This step is done after all the wood is squared.

A. Tracing

The central axes of the elements are drawn with chalk on the floor of the workshop.

B. Mise sur Ligne

The squared wood logs are stacked on the lines of L’»Épure», elevated on small benches. One can control that the elements are well aligned to the drawing using a plumb line. Where the timber elements cross, joints symbols are added on the floor and on the wood. Timber structures are cut in the right dimension to fit the framework.

C. Joint

Joints are drawn on the timber elements and they are carved with chisels and saws.

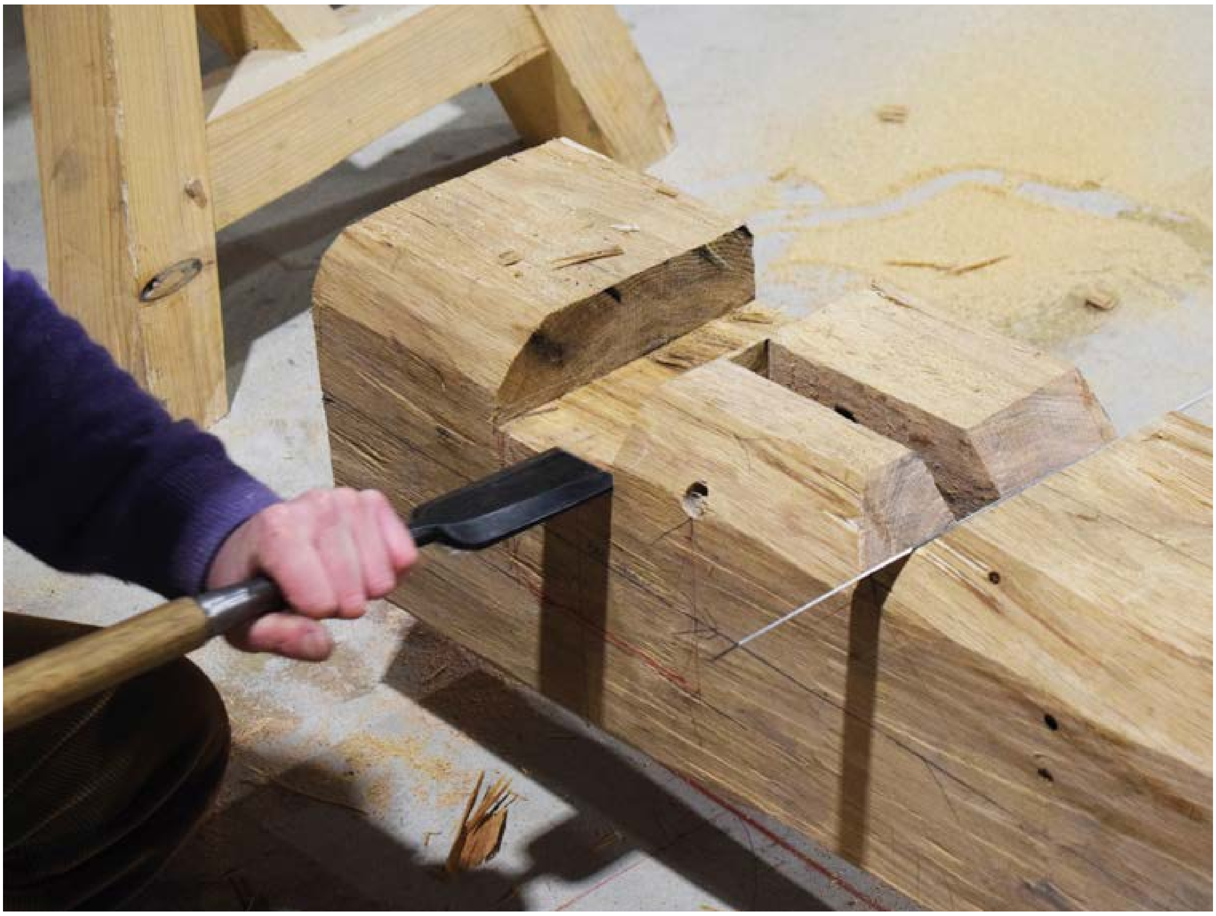
D. Assembling

When all the joints are carved, the whole framework is assembled for further adjustments.
In the case of Notre Dame, the large frame fitted just right in the workshop.

Machines

Wood joints like mortise are usually difficult and annoying to make by hand. The “Atelier” uses mortise machines to create the notches and the finishing is done by hand. Paul Zahnd underlines the importance of finishing by hand to create curvatures and absorb deformations of the whole framework.


ENTRAIT 6m

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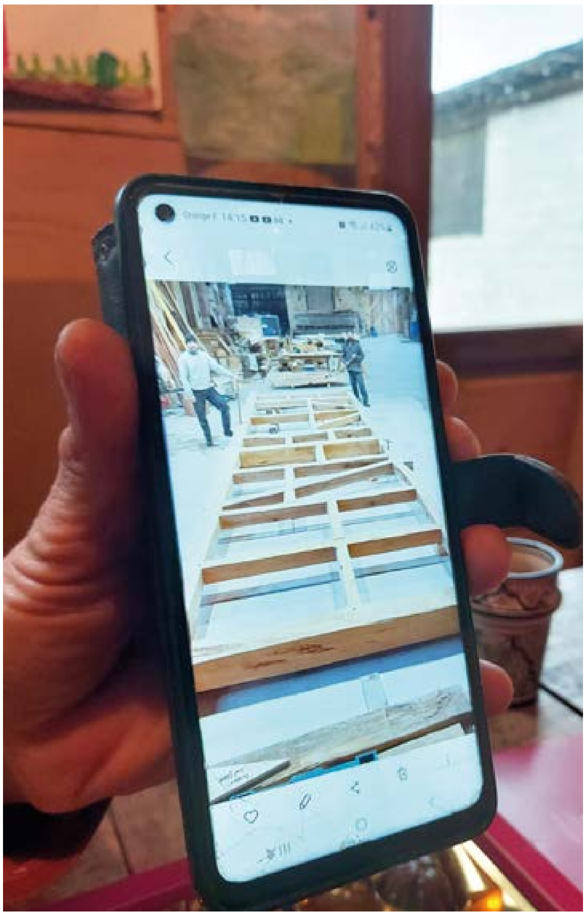
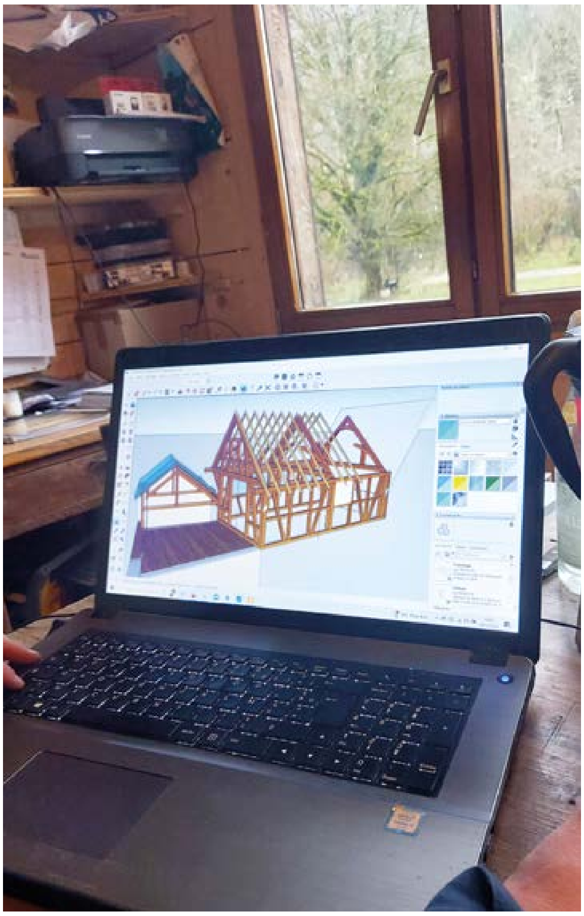




IV. Construction

After the carpenters were done with the frames of the Cathedral, they sent them to the "Atelier Desmonts" in L'Eure. All the 46 frameworks were assembled and mounted together in a single workshop to check if it all fitted together. The frames were mounted with pulleys and pulled by groups of carpenters. The frames have a width between 14 and 16 meters, for a height between 12 to 13 meters. The beams have sections around 18cm.

Rebuilt

The destroyed roof dated from the 13th century and the tower from the 19th century. The project was fully modeled in 3D. The carpenters designed adapted assemblages for the structure. They then collected the needed timber. In parallel, engineers calculated the needed sections and dimensions. The framework is a Chevron Formant Ferme, which is a large triangular roof structure. It has a pair of Arbaletrier forming the triangular shape, an Entrait on the horizontal direction and a Poinçon in the vertical direction.[84]
The same frame is repeated with the same assembly and production process. Afterwards, the whole construction was sent to Paris and assembled with cranes on site. After the framework was mounted, plumb covers were put to protect the monument from rain.

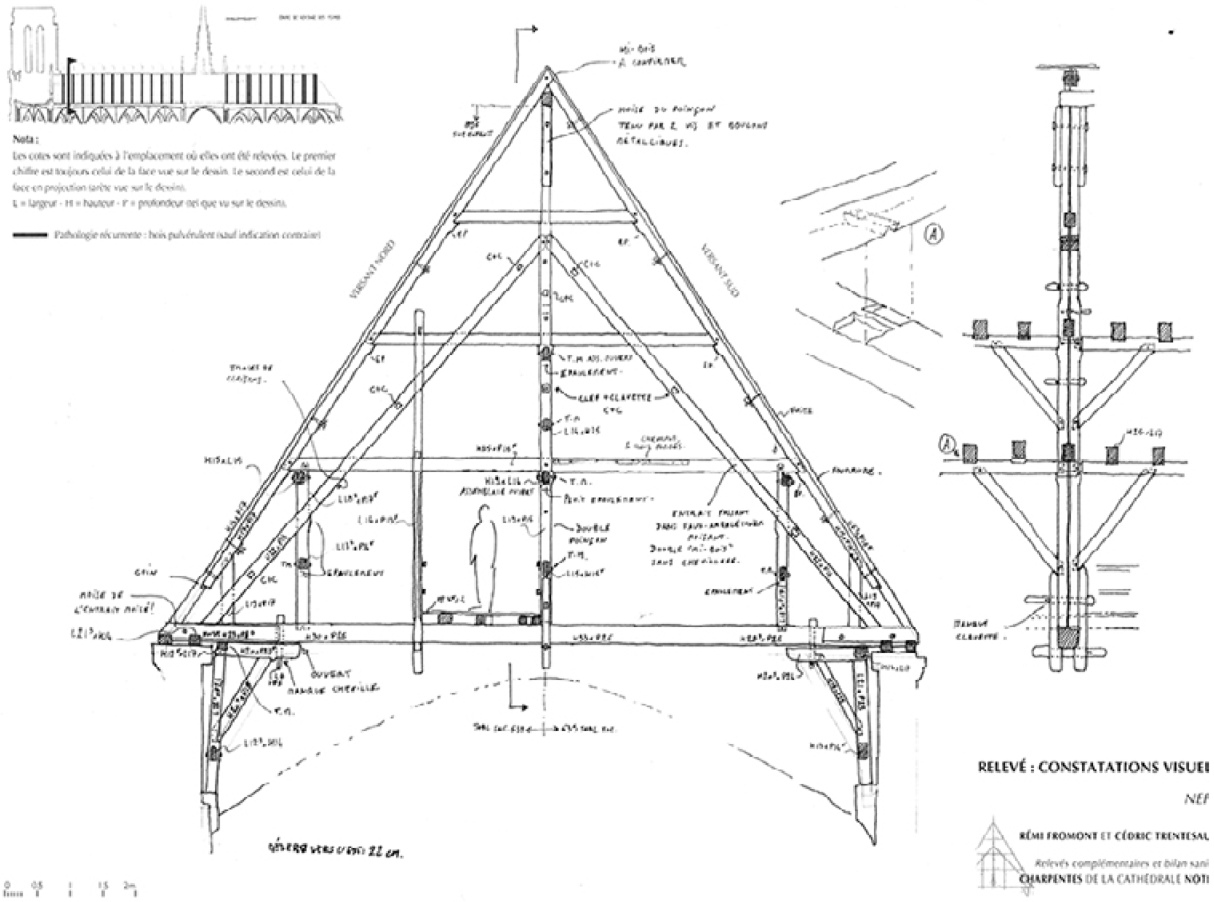
Rebirth

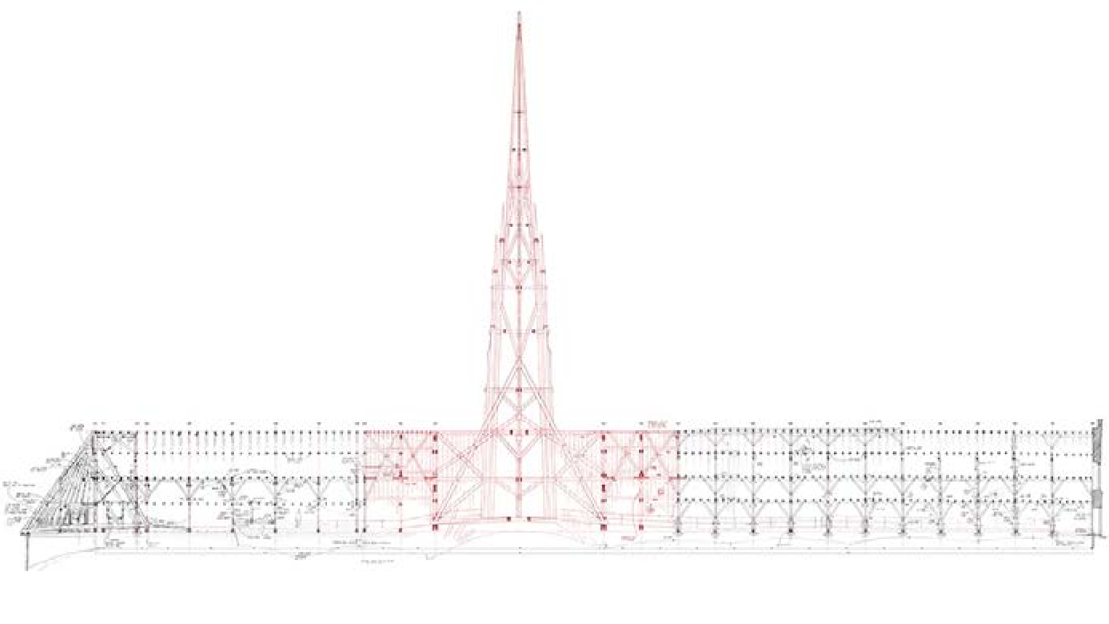
The reconstruction renewed the interest in artisanal construction and Green Wood Squarring. It showed the esthetical and technical value of working with hand tools. Fibers were respected with the ax. The surface of the wood was non delignified and it was more structurally and water resistant. Moreover, the historical method produced less waste by keeping trunks in one element.

Distance

One can, however, question the large distances that were traveled by the timber. The trees were first imported from different regions: Alsace, Centre val de Loire, Île de France and Bourgogne Franche-Comté. Then, they were sent to 3 different carpentry workshops. Not only did it produce more CO2, but the squared wood also developed deseases and weaknesses which are abnormal for oak trees.
The 1' 300 trees, obviously, needed to be sourced from different places. The French president promised a reconstruction in 5 years, and no forest can produce so much wood in so little time. The method is not to be questioned entirely, but it is clear that the production of such large monuments always has negative consequences on one aspect. At least, all the trees originated from France which is a good start for local sourcing.

84. Etablissement public., 2023





85. Fromont , 2014b
86. Fromont , 2014a

87. 

 88.

89. 

87. Atelier de la grande oye, 2023
88. Compoint, Le Pélerin, 2023
89. Compoint, Le Pélerin, 2023
90. Map made with Google Earth, 2023

Conclusion

The Notre Dame reconstruction project provides a notable example of the resurgence of artisanal construction methods, specifically the use of hand tools and traditional practices. The incorporation of historical techniques, as demonstrated by individuals like Serge Turberg and Paul Zahnd, reflects a dedication to preserving cultural and historical values within the construction process.
The application of green wood squaring has the potential to enhance aspects such as reduced transport, minimized wood waste, and the utilization of carpenters' skills. The application is, however, consequently viable on small projects. Negative impacts seem, in fact, unavoidable when making large scale projects.

Competitive wood squaring

The implementation of wood squaring in small-scale projects appears to be feasible for the "Atelier de la Grande Oye."
Carpenters at "La Grande Oye" not only make construction decisions but also actively participate in every stage of the project, from inception to completion. Moreover, the ir house-sized projects that incorporate curved wood can further diminish transport and energy consumption. The project results in lower CO2 emissions and waste, and the processing costs are significantly reduced. Meanwhile, industrially cut spruce wood prices have risen due to the impact of the bostryché and the global warming.
Despite higher labor costs, "La Grande Oye" achieves comparable price levels to industrially cut wood.

Big projects Big consequences

Despite the potential of Notre Dame to revive wood squaring, the inherent advantages are compromised by higher complexity. Instead of utilizing inexpensive curved wood, the project required large century-old oak trees. Consequently, the wood had to be transported over long distances, and unexpected diseases emerged.

Hand and Machine

In realistic contemporary production, machines played a role in both situations. While preserving the benefits of wood squaring and the autonomy of workers, the use of machines, in conjunction with manual labor, allowed for increased efficiency.

Wood squaring holds potential for the wood industry, but its advantages must be strategically harnessed. Machines can help offset labor costs, but careful consideration of the application steps is essential to prevent the deskilling of workers.

		Steps	Tool	Enhancements
I.		Selection		
II.		Squaring		
	A.	Tracing	plumb line	
	B.	Nicking	ax	chainsaw
	C.	Smashing	ax	chansaw
	D.	Finishing	single-bevel ax	
III.		“Épure”		
	A.	Tracing		
	B.	Mise sur ligne	plumb line	mortise machine
	C.	Joint	chisel	
	D.	Assembling		
IV.		Construction		

Machine and Hand

Tools

Process

What happens when Machines are introduced in Wood processing?

An exploration of the predominance of machines over hand tools in processing and its implications on the socio-economic context. The chapter will highlight the increased need for transportation, escalated waste production, and the diminishing skills and autonomy granted to carpenters. The period will commence in the 15th century, intensifying from the industrial revolution to the present day. The research will draw on examples and texts from around the world, considering the global nature of the development.

The Tools chapter will dive into the evolution of machine tools, drawing on historical description and a discussion with toolsmith Serge Turberg.

The Processing chapter will follow the industrial processing, from log to construction through the use of eternal devices. The case of the construction of the Tower of Malley will be studied. This exploration is drawn from visits to the forestry rangers in Ropraz, the sawmill of "Scierie Zahnd", the factories of the construction company JPF-Ducret and visits to the construction site of the Malley tower.

Mechanization, Precision, Productivity

A machine can be distinguished as a device that can substitute human power by external power.[91] The subsequent era is distinguished by its introduction in production, which triggered a transition from a manual-reliance craft to a mechanized workflow.

Certain construction machines, such as lifting machines used in the Roman Empire since the 1st century BC, [92] and water sawmills dating back to around the 15th century, already existed. However, they couldn't supersede the dominance of manual labor until the Industrial Revolution in the 18th and 19th centuries.

For certain tasks, the processing of wood demanded forces within the limits of human muscles; consequently, simple machines were introduced at an early stage.[93] Furthermore, traditional wood squaring was humanly tolerable for larger-sized elements, easily achievable with an ax. However, the conversion of wood into thinner elements required too much time and effort with only hand tools like free-hand saws or splitting wedges.[94]
As stated by Jean-Pierre Adam in “La scie hydraulique de Villard de Honnecourt et sa place dans l’histoire des techniques”:

“The enormous quantity of wood needed for monumental roman programs, the production of construction site machines, the need for fast execution, are so many arguments that demanded a research for mechanization of wood cutting.” [95]

The initial devices could be categorized into a power machine providing the energy to generate an effort and a performing machine responsible for carrying out the desired task.
Machines’ economy and efficiency were accelerated by the introduction of steam power and coal. Sawmills appeared on a global scale and the open market rendered hand labor uncompetitive.[96]
Finally, the process was globalized, reshaping completely the world till today.[97, 98]

91. Schindler, 2009, p.95
92. Adam, 2005, p.14
93. Schindler, 2009, p.130
94. Adam et al. 1985, p.318
95. [translation] Adam et al. 1985, p.317
96. Richards, 1875, p.2
97. Schindler, 2009, p.138
98. Stearns, 2013, p.2

From Curved to Standardized Wood

Around the 18th century, the use of woodlands transitioned from state management to legal ownership and became integrated into the market.[99]
Sawmills, unable to use curved woods, replaced them with standardized straight pieces. Certain wood species like spruce wood proved more suitable for industrial production, because they had long straight consistent trunks and rare deformations.
In the 19th century, monoculture of one or two wood species increased as a result. The reduction in biodiversity led to a decline in the regenerative capacity of forests.[100]

From Local use to Open Market

One limitation of sawmill production was its fixed position. Water sawmills were frequently constructed on rivers situated at the bottom of hills. In consequence, the manufacturers' production couldn't increase due to restricted transport.
In the 19th century, the emergence of universal motors, such as steam engines, separated production from exploitation by substituting water movement with a more versatile source of energy. The utilization of coal and the advancement of trains and other novel modes of transport facilitated the open market to sell wood anywhere. [101]

From Skilled Carpenter to Workers

Hand work is a double sided blade: on one hand it presents infinite adaptability and flexibility; on the other hand, the repetition of two consecutive movements is theoretically impossible. Applied strength is, furthemore, limited by human capabilities, while machines can exponentially grow in power.

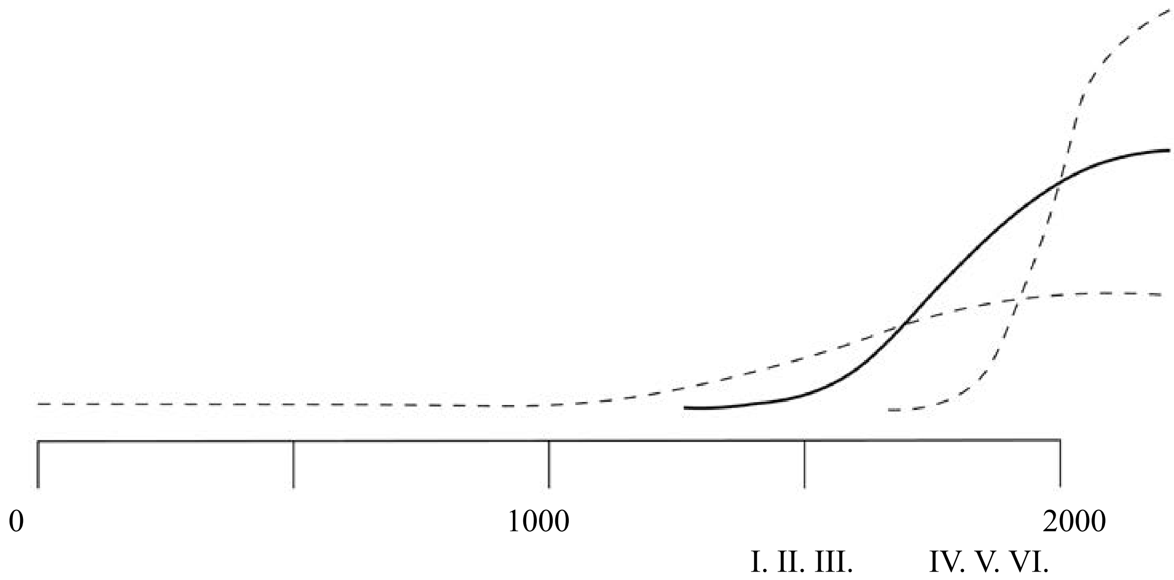
The sawmills, despite facing worker opposition and vandalism initially, greatly increased precision and facilitated the production of flat and consistent profiles.[102] The introduction of band sawmills, however, led to the need for organized company structures due to increased productivity, posing challenges for the artisans.[103]

The industrial revolution marked a shift toward deskilling workers through the subdivision of labor, mechanization, and scientific management.[104] Craft skills involving autonomy and control diminished, and tasks were redistributed to reduce overall costs.[105] Working hours also increased significantly during industrialization.[106]
The separation of design and execution further contributed to the deskilling process.

99. Grewe, 2011
100. Kola et al. 2021, p.2
101. Schindler, 2009, p.138
102. Peterson, 1973, p.85-86
103. Schindler, 2009, p.135
104. Shields, 1995, p.1
105. Crawford, 2009, p.49
106. Gilmore, 2023

Tools

107.



I. Nature-powered Sawmills
II. Gang Sawmills
III. Steam Sawmills
IV. Machine-Tools
V. Numerically Controlled Machines
VI. Robots

The following chapter will focus on the appearance of machines throughout history and their impact on the environment and socio-economic context. The study is based on historical texts and descriptions and discussions with toolsmith Serge Turberg.

A machine can be distinguished as a device that can substitute human power by external power.[108] The device can be divided into two entities:
A power machine produces or absorbs energy from natural movements and fuel.
A processing machine transforms the energy or the motion into working movement.
The following period is characterized by its introduction which provoked a shift from a manual craft to a mechanized workflow.

107. Adapted from graph, Schindler,2009,p.88
108. Schindler, 2009, p.65

I. Nature-powered Sawmills

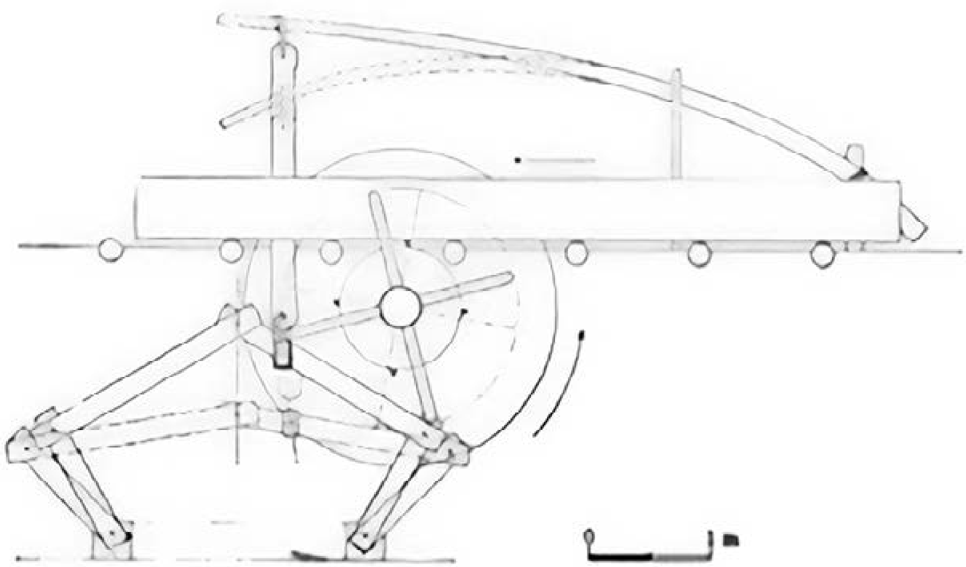
Sawmills started appearing between the 15-19th century with the development of saws and transportation.

Water-Sawmill

Despite its irregular flow, water is together with the wind a first example of a free and unlimited non-human energy that was available already in the Middle Ages.[109] It was a wheel, turning with the flow of water, first used for grain mills. Early applications of water-powered sawmills are, however, difficult to date, with writings only mentioning it, until the 13th century with the carnet de Villard de Honnecourt which had precise and complete drawings.[110] The broad production, however, of saws and iron gears couldn't happen before the appearance of larger ovens in the 15th century as discussed in the Hand chapter.[111] From the 16th century, the application of sawmills also appeared in the Netherlands, using wind to power machines.[112]

Productivity

Around that time, the total production of a saw machine would be up to 900m3 per year which is roughly 10 times superior to the productivity of a two-people hand saw and the precision increased going from wavy shapes of the human hand to flat and consistent surfaces.[113]


114.

109. Adam et al. 1985, p.318
110. Schindler, 2009, p.131
111. Turberg, 2023b
112.-113. Schindler, 2009, p.133
114. Image taken from Adam et al. 1985, p.320

Transport Restriction

The power machines, however, were still restricted to specific meteorological situations, linked with many changing factors, such as water flow, erosion and bank movements.[115] The machine was often stuck at the bottom of hills, far away from woodlands.[116] This restricted transport at the time didn't permit the sawmills to outcompete wood squaring until the 19th century.

Waste

A first consequence of the use of sawmills is the inability to manufacture curved wood. The log is pushed straight on the machine and nothing can inform it yet of variations. In consequence, curved wood was trashed or used for heat and other purposes.

Increasing Woodland Exploitation

During the Middle Ages, wood was a material impossible to replace as it was used for heat, construction, furniture, carriages and tools.[117] Depending on the local availability, each wood species was more adapted for different uses, softwood for board construction elements like framing, scaffolds, floors etc. and hardwood for interiors, paneling, doors, furniture and heavy load bearing structures.[118] Until the 18th century, forests were therefore, biologically very heterogeneous, and its exploitation was controlled by the state and organized by collectivities which sold it in local markets.[119]

Carpenters Opposition

The increasing productivity of band sawmills demanded company sized organization, to the extent that producers perceived it as a threat and vandalized sawmills.[120] The introduction of the first sawmill in England in 1663, for instance, was followed its abandonment shortly after because of workers' opposition and the second attempt in 1767 was burnt down by artisan mob.[121] Machinery came at the cost of skilled artisans, as more machines were built where labor was more expensive.[122] As a result, the price of the product was reduced , making it competitive with other sawmills.[123]

115. Adam et al. 1985, p.319
116. Grande Oye, 2023
117. Grewe, 2011
118. Miller, 1999, p.2
119. Grewe, 2011
120. Schindler, 2009, p.135
121. Peterson, 1973, p.85-86
122. Richards, 1875, p.2
123. Richards, 1875, p.2

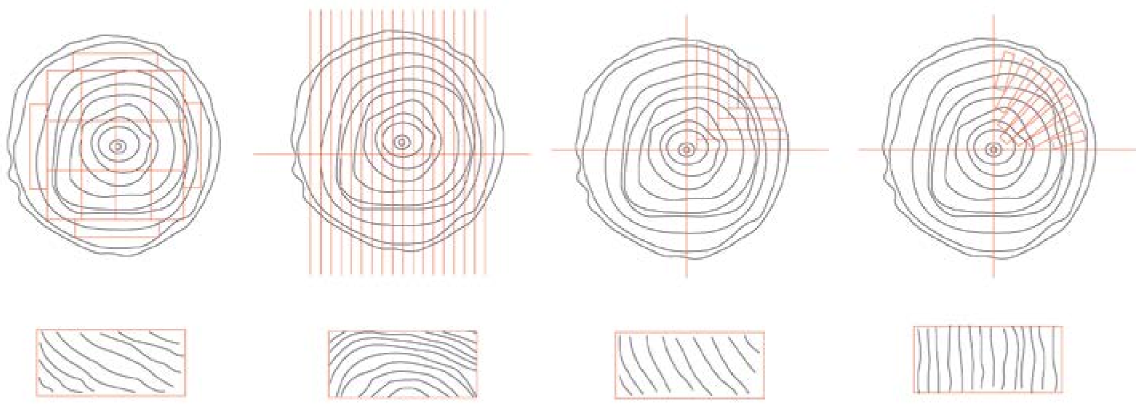
II. Gang sawmills

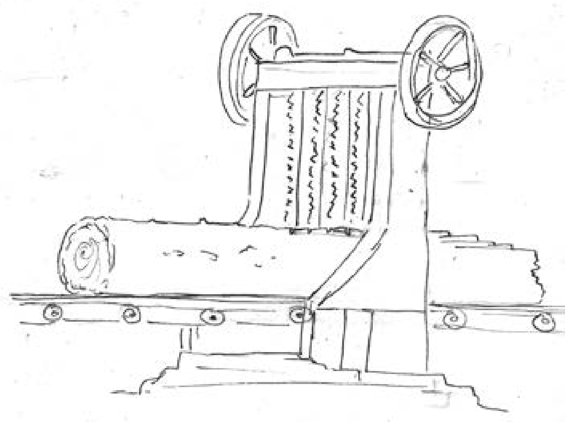
Gang sawmills emerged between the 16th-18th century, facilitated by advancements in iron production.

The rapid development of nature-powered saws began spreading in several places ; Germany 1332, Madeira 1420, Holland 1569 and Sweden 1658 ; [124] and evolved further with technological advancements. One of the first gang-saws was built on the Danube in 1575 with multiple band saws dividing a trunk into many planks in one operation.[125] From the 15-18th century, evolution in steel making helped putting up to 6 blades on the saws.[126]

Lumbered Wood

Advancement of gang saws increased considerably the productivity with the possibility to make more lumber.[127] With sequencing of gang saws, wood lumbered in 4 ways drawn in the illustration bellow: Plain-sawn, subdividing squared wood into smaller planks ; Live-sawn, simply cutting wood into parallel strips ; Quarter-sawn, cutting wood in four and subdividing the quarters into orthogonal subdivisions ; and Rift-sawn, cutting the quarters radially.[128] Plain-sawn wood, for instance, is simpler, cheaper to produce, but it has less structural resistance and makes different types of grain patterns.[129] Quarter-sawn wood is more labor-intensive however the grain directions give better moisture and structural resistance.[130] Finally, Rift-sawn wood is the most complicated but also the most resistant of all cutting patterns.[131]





124. Peterson, 1973, p.85
125. Peterson, 1973, p.85
126.-127. Schindler, 2009, p.134
128-131. Rosasco, 2016

From Wood Squaring to Standardization

The system allowed to predetermine different board thicknesses, but it needed manual calibration as information was not yet implemented in the machines.[132] So to avoid technical limitations, the use of standardized or normed profiles was imposed and the productivity increased up to 1800m3/year.[133]

Waste

Depending on the chosen lumbering division, larger quantities of cutout waste were generated because of the saw's thickness. The wood is cut in its center and not only on its skin like wood squaring.

From Forest to Factory

Subsequently, the doubled productivity required for new organizational approach and led to the introduction of the first factory-structured companies in wood production.[134]
The naturally diversified characteristics and the multiplicity of different processes available for wood conversion, however, rendered the application of repetitive rules to organize factories difficult.[135] Machinery, fire danger, sawdust and heavy machines, moreover, demanded more strong buildings than the wood sheds constructed previously.[136] The production was still not sufficiently prolific to be considered industrial and global, as it was limited by irregular flows and geographical positions of wind and water, and production was not yet fully mechanized as some steps still relied on hand work.[137]

From Woodland Communities to Open market

With globalization of technology, together with an augmenting population, cooperative control of wood turned into an open market.[138] Already in areas overexploited there was noticeable reduction in woodland regeneration.[139]
Additionally, the great variety of wood was replaced by monoculture softwood forests, all with the same height and same age.[140] Species like spruce known for their rapid growth and long, straight tree trunks, are particularly well-suited for adapted to standardized construction.[141] This new type of woodland was easier to plan and control, making exploitation more efficient. Density was increased and in the darkness, unwanted species disappeared.[142]

132.-134. Schindler, 2009, p.134-135
135. Richards, 1875, p.23
136. Richards, 1875, p.23-24
137. Schindler, 2009, p.135
138. Richards, 1875, p.2
139. Grewe, 2011
140. Grewe, 2011
141. Larsen, 2022, p.495
142. Grewe, 2011

III. Steam Sawmills

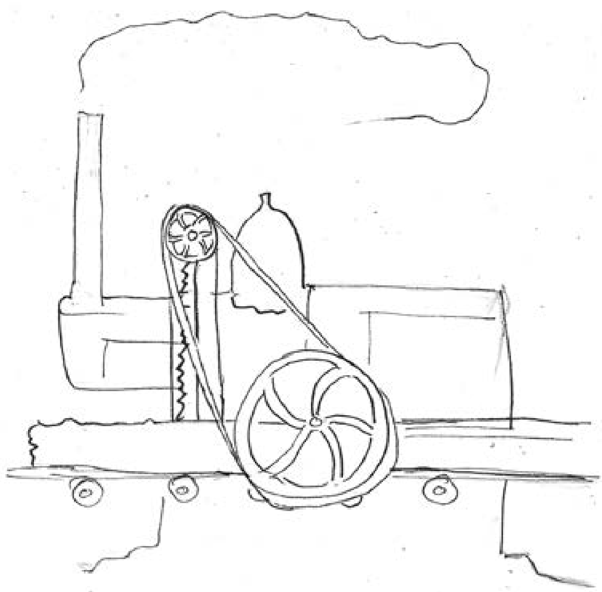
Steam sawmills, with the use of coke fuel and transport, appeared around the 18th century.

Steam Engine

The first steam engine was introduced in the textile industry in 1712 by Thomas Newcomen. It consisted of an universal motor unrestricted to natural sources, by relying on harnessing hot energy from a burning source like wood, charcoal or coal.[143] It took, however, at least until the 19th century to make it universally relevant.[144] In 1803, a steam machine of one of the Steam machine pioneers, Oliver Evans, was connected to an existing water-driven saw-frame, which proved to be more reliable and productive.[145] Around 1811, a patent written for Evans sawmills and Steam-powered sawmills, started spreading in the USA, making it a leader in woodworking.[146,147]

Productivity

In the 18th century with the conversion of coal into coke by Abraham Darby, helped to achieve making stronger steel.[148]
Thanks to its incomparable precision, loading capacity, abrasion resistance and elasticity,[149] iron replaced wood for construction of saw machines, which enabled better transmission of movement between power machine and performance machine. It increased the productivity to 6500m3 per year.[150]



143.	Schindler, 2009, p.138
144.	Schindler, 2009, p.141
145.	Peterson, 1973, p.87
146.	Peterson, 1973, p.88
147.	Schindler, 2009, p.142
148.-149.	Schindler, 2009, p.138
150.	Schindler, 2009, p.143

Patents

With the advance of technology, more patents were written specifically in the wood industry, so many that the exclusive uses might also have made advancement in that period slower. It made the market unequal and has still consequences today.[151] Even patent free-regions gave some concession prices to selected firms like Scandinavian governments in the 18th century.[152]

Transport

Around the 19th century, new ways of transport were invented, thanks to iron, coal and coke developments, to move wares around the global market, like trains and steamboats. Sawmills could produce from anywhere losing the disadvantage regarding wood squaring but increasing CO2 emissions.

Drying Wood

Even in the Middle-Ages, carpenters would sometimes let the wood dry naturally for 6 to 12 months to avoid deformations, but the application was rare as dry wood was more difficult to transform with an ax.[153]
The use of sawmills and the application of standard dimensions was however hard to make completely consistent with green wood.[154] Over time, materials undergo dimensional changes and deformations due to the gradual release of internal moisture.
From the 19th century onwards, new ways of active drying with heat and air, like Kiln Drying, permitted faster and consistent moisture reduction.[155]

From Carpenter to Worker

The Industrial Revolution marked a gradual process of deskilling among the artisans through the subdivision of labor, the mechanization of tasks and the application of scientific management in manufacturing.[156] Following Taylor's writing, the artisanal activity was absorbed and redistributed in different tasks to reduce adjustment time and overall costs.[157]
Harilal, proposes measuring deskilling by dividing the ratio between skilled carpenters and unskilled carpenters' wage. He noticed dropping numbers in India since the industrial revolution.[158] It might however be due to factors other than mechanization. Glimore, gives furthermore measures of working week in manufacturing from 1820 to 2010 in England. Working time increased from 250 to 300 days per year with daily work of 10-12 hours.[159]

151. Richards, 1875, p.19
152. Richards, 1875, p.2
153. Grande Oye, 2023
154. Schindler, 2009, p.173
155. Youngs, 1967, p.49
156. Shields, 1995, p.1
157. Crawford, 2009, p.49
158. Harilal, 1989, p.134
159. Gilmore, 2023

IV. Machine tools

Machine tools appeared between the 18th-19th century with the perfection of steel.

Globalization of sawmills in Europe and America opened the market and forced competitiveness between the firms, making hand work irrelevant, only used for finishing until the 19th century.[160, 161] Many changes in the economy and technology society occurred between the 18th and 19th century in Great Britain, driven by iron availability, coal use and machine tools.[162] They are fully harnessed iron built machines, producing rapidly, precisely and cost-efficiency, wood and iron conversion tools, machine parts, driving exponentially the mass production industry. Numerous iron tools with precision needs were thus integrated in machine tools, most of them with patented inventions :

Circular Saw

Only made possible with precise iron making, a circular saw rotating and making a continuous guided cut, but was first used for small sections as large ones were better suited for gang saws.[163, 164] *(n°1 page 70)*

Planer or Milling Machine

A machine with circular saws placed parallele to make clean surfaced, or create laminated wood.[165, 166] *(n°3 page 70)*

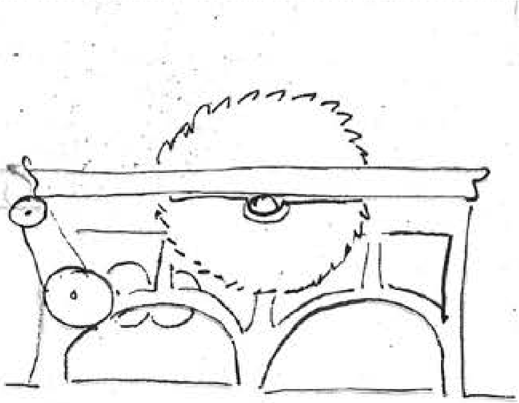
Copy Mill

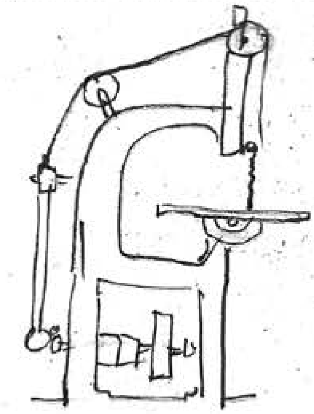
At the end of the 19th century, a precursor of the integration of information in machines emerged in the form of the milling machine. This innovative device was capable of crafting 3D objects and carving ornaments with a high speed rotating drill, guided by a template or a stencil. It had the remarkable ability to replace the work of 2000 carpenters with one operator.[167] Starting in the United States during the 1880's and the 1930's, a switch between direct raw energy use from coal to the use of processed energy forms like combustion fuel and electricity, enhanced the autonomy of machines.[168]
(n°5 page 70)

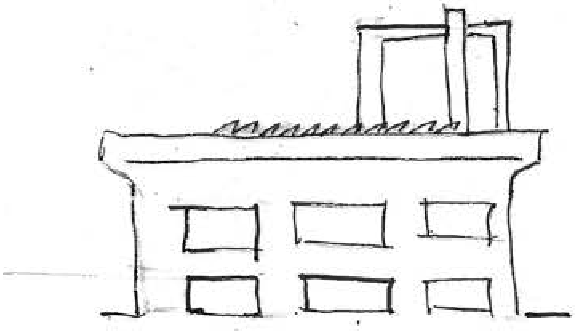
Steel Connectors

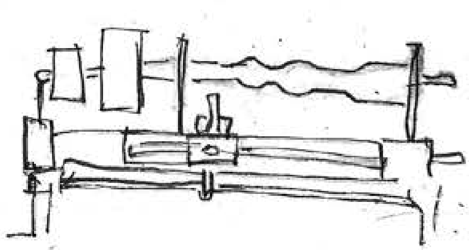
Thanks to coal and cheap iron conversion, machine-tool produced effectively tools, machine pieces and steel connectors.[169] Soon, nails, dowels and sheets, replaced complicated artisanal wood-wood connections.[170] Sections could be cut with a flat surface making the production faster.

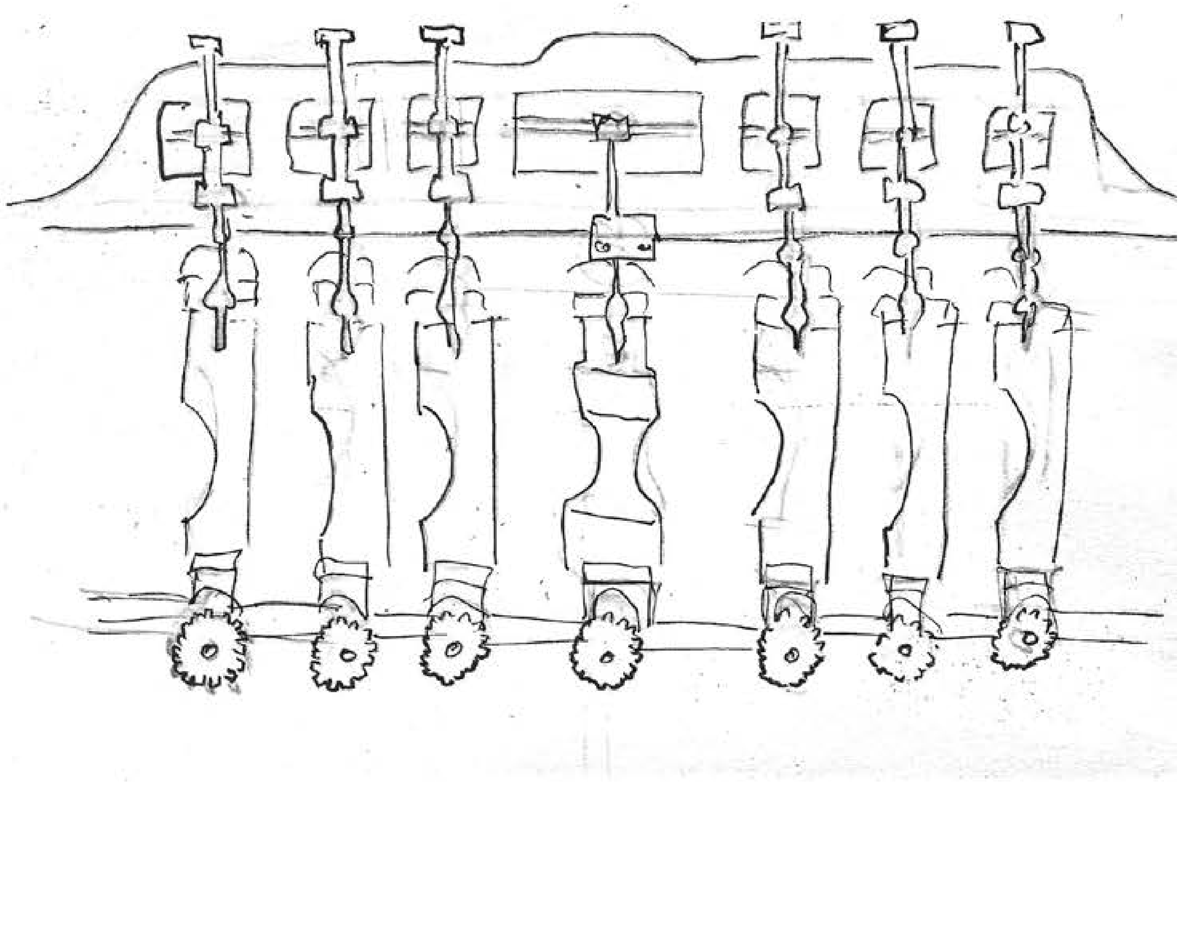
160. Richards, 1875, p.2
161. Schindler, 2009, p.139
162. Schindler, 2009, p.136
163. Schindler, 2009, p.139
164. Curtis, 1973, p.163
165. Schindler, 2009, p.144
166. Wallace et al. 1929
167. Schindler, 2009, p.153
168. Warren, 1983, p.374
169. Schindler, 2009, p.139
170. Schindler, 2009, p.163











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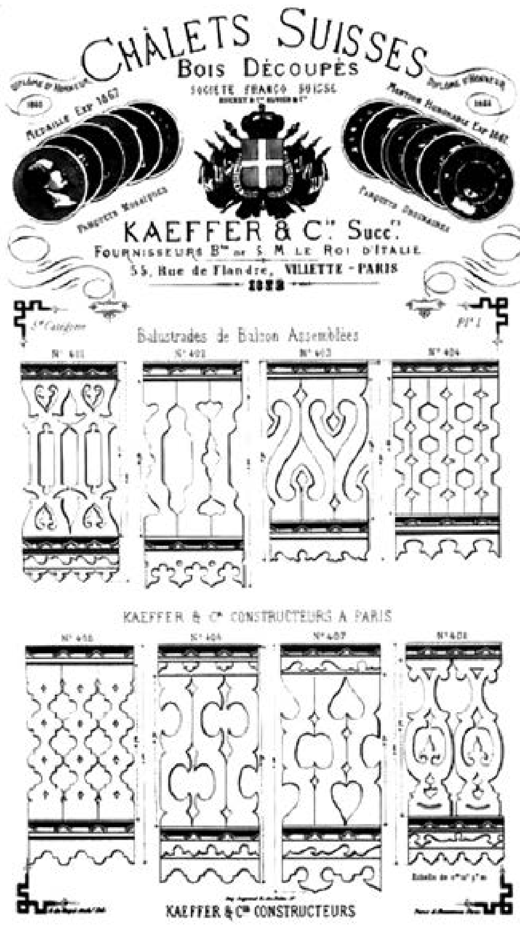
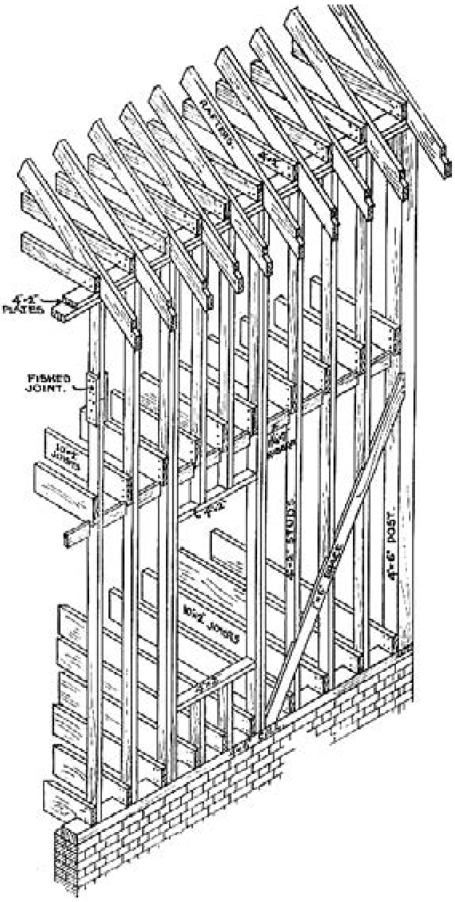

CHALETS SUISSES
BOIS DÉCOUPÉS
KAEFFER & C^ie Succ^rs
FOURNISSEURS B^tes DE S. M. LE ROI D'ITALIE
55, Rue de Flandre, VILLETTE - PARIS
Balustrades de Balcon Assemblées
KAEFFER & C^ie CONSTRUCTEURS A PARIS
KAEFFER & C^ie CONSTRUCTEURS

172.


4"×2" PLATES
FISHED JOINT.
4"×6" POST.

The implications of machine-tools were, however, depending on the socio-economical context and on the way workers were involved in the design.

Ornamental Style

On one hand, copy-mil cut ornamental elements through the use of templates and models. Hand work was minimized but was concentrated in the making of the model similarly to etching reproduction.[173] The Swiss traditional style of the 19th-20th century, for instance, made use of the saw to efficiently incorporate elements while making use of one crafters skills and putting it into the design process.[174] *(n°1 page 71)*

Two-by-Four

On the other hand, machine-tools helped produce precise and consistent ornamental 2 by 4 profiles. During the rapid housing construction in the 1830 in America, the use of balloon frames proved to be extremely efficient with For instance 3 ‘000 houses built in Cheyennes in 1876 using this construction method. Those were frames made of 2x4 profiles constructed on the ground, lifted and braced with horizontal bars and panels.[175] The suppression of ornaments on elements and the use of iron connectors replaced the complicated artisans’ wood-wood connectors and simplified section cutting.[176] *(n°2 page 71)*

171. Image taken from Schindler p.170
172. Image take from Chisholm, 1911
173.-174. Schindler, 2009, p.169
175. Schindler, 2009, p.168
176. Schindler, 2009, p.163

Numerically controlled machines appeared in the middle of the 20th century, thanks to information storage.

Information Storage

The mechanical principles of wood processing with machine-tool technology have remained unchanged from the entire period referred to as industrialization until today.[177]

Following the invention of electrical motors, the beginning of the 20th century brought new types of electrical copy machines. They had the ability to scan models and autonomously reproduce them. The machines were however too slow and couldn't be industrially scalable, because the transmitted information still required manual physical input.[178]

Developments in micro information storage in the 20th century, however, permitted including information without manual template making. Transistor and microchips in the first calculators of the 1930's and electronic computers in the 1940's,[179] made the information processing scalable in the industrial paradigm.

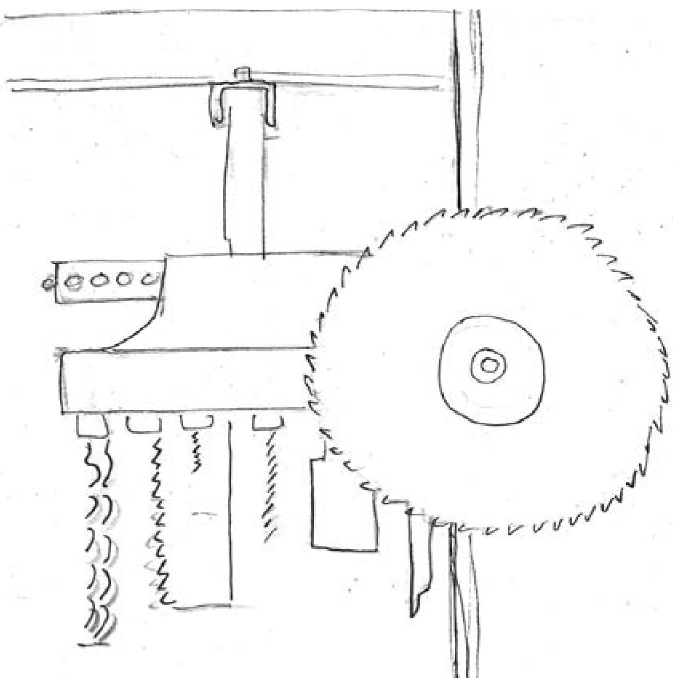
NC

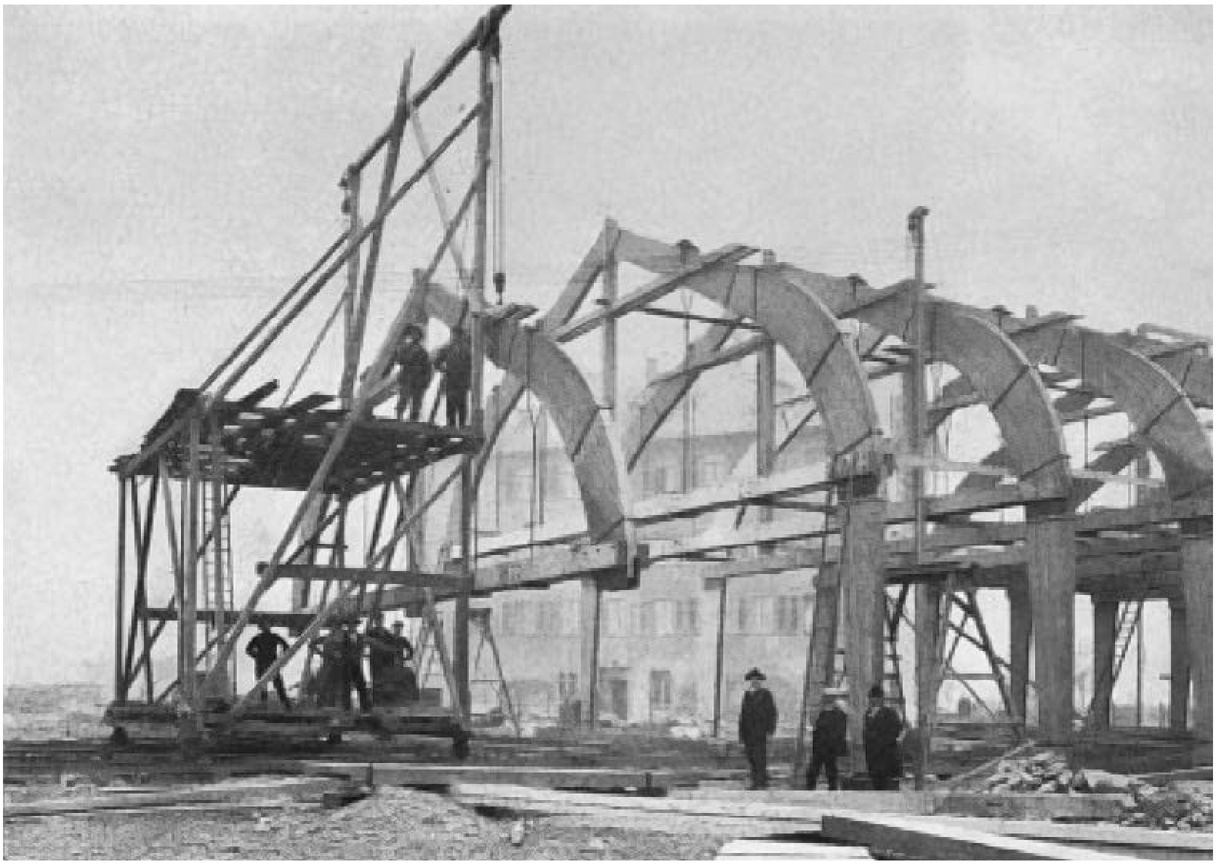
At the end of the 1940's, the engineer John T. Parson manufactured helicopter rotors by the use of machines informed by punch cards, giving out instructions like drilling out complex aerodynamic curves.[180] Those were numerically controlled storages giving instructions to performing machines. Further advancement made use of computer numerical control to give direct instructions to milling machines, making it more flexible, cheaper, and financially viable for medium-sized companies.[181] Since the 1970's the use of numerically controlled machines in the woodworking production surged. In the 1980's half of the timber construction companies used it.[182]

All Purpose

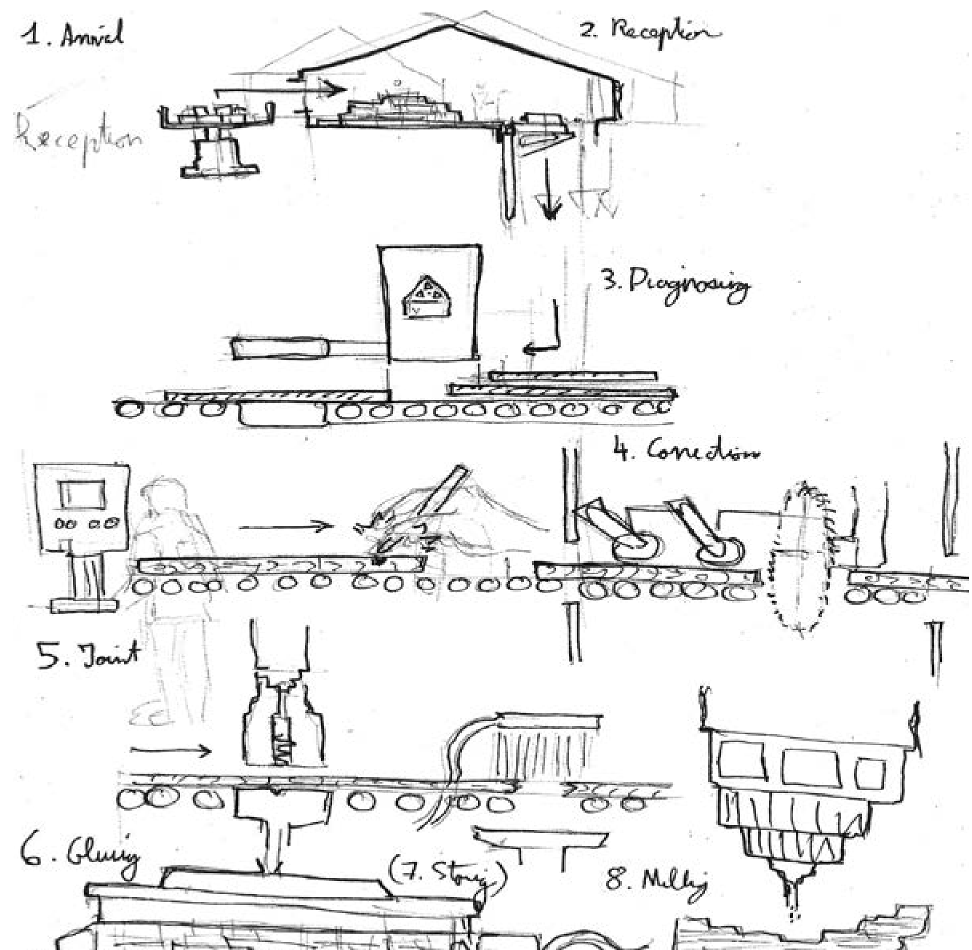
The span of usable tools as machine tools was high, like drilling, milling, sawing, for plate and joinery making, but all were integrated and automatically changed and operated without interruption giving the name of machine center.[183] These all purpose machines integrated nearly all types of possible wood-processing, and the flexibility offered was higher than precedent machines or tools, making it closer to the human hand adjustability.[184]

177. Schindler, 2009, p.156
178. Schindler, 2009, p.155
179. Schindler, 2009, p.187
180. Schindler, 2009, p.189
181. Ferguson, 1978, p.91
182. Schindler, 2009, p.193
183. Ferguson, 1978, p.90
184. Schindler, 2009, p.203





185.


1. Arrival
2. Reception
Reception
3. Diagnosing
4. Correction
5. Joint
6. Gluing
(7. Storing)
8. Milling

Waterproof

The application of standard dimensions and precise machinery was hard to make completely consistent.[186] Wood is an organic material which is characterized by hygroscopic and anisotropic characteristics that vary throughout the different species.[187] The visual sorting of sawn timber to apply on an industrial scale, was only possible in the 1970's.[188]

In the beginning of the 1900's new waterproof glue revolutionized the production of wood.[189] Not only did it protect wood from outdoor conditions like fungus and humidity damages, but it developed a new range of wood products with completely homogenized features and stability of dimensions and deformation. These products include Chipboard, Medium Density Fiberboard, Plywood and Glued Laminated Timber (Glulam).[190]

Glulam

In 1906, Otto Hetzer obtained a patent for glued laminated timber,[191] and the firm Terner & Chopard obtained the exclusive right of the applications in Switzerland.[192] It consisted of laminating wood before gluing it together. It produces around 35% of cutout waste.[193]

Contemporary use applies then CNC machining for finishing andjoints. Glulams range from Plywood Laminated Veneer Lumber (LVL), Laminated timber, and Cross-Laminated timber (CLT).[194] Greater stiffness was attained as well as longer and larger sections than with natural wood logs.[195]
The first application of glulam structures in Switzerland were girders, 5 m long arcs made out of wood planks, connected by an iron articulation.[196] It was popularized as an economical alternative to steel structures.[197] This meant the reemergence of timber as a large-scale construction material.[198]

Big Entreprises

All the processing, however, implied prefabrication that was done in factories or workshops. The prefabrication and processing, from laminating the wood, to gluing and assembly, demanded contractor companies that would be able capable of overseeing and managing the entire production chain.[199] The enterprises went from only managing construction to making a project from a to z. It affected many contributors in the field, leading to the dominance of construction companies in the Swiss Wood industry nowadays.

185. Image taken from Haddadi et al. 2021, p.503
186. Schindler, 2009, p.173
187. Correa et al. 2019, p.72
188. Schindler, 2009, p.173
189. Schindler, 2009, p.175
190. Correa et al. 2019, p.68
191. Schindler, 2009, p.174
192. Haddadi et al. 2021, p.502
193. JPF-ducret, 2023
194. Correa et al. 2019, p.68
195. Svilans et al. 2019, p.96
196.-197. Haddadi et al. 2021, p.502-503
198. Svilans et al. 2019, p.95
199. Haddadi et al. 2021, p.503

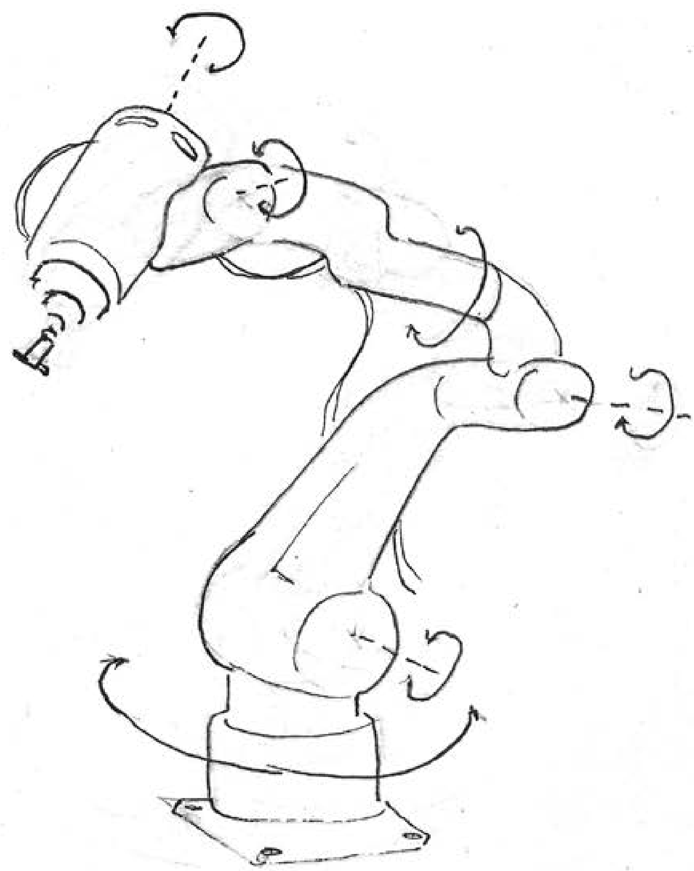
VI. Robots

The advent of robots in the 20th century can be attributed to advancements in information storage. Their development was not driven solely by necessity but rather by a deliberate choice.

In 1961 George Devol and Joseph Engelberger patented a large automated armed-shaped machine used for transferring objects from one place to another,[200] first introduced in assembly lines of the car industry.[201] The miniaturization of processors and motors changed the main aims in the early 1970's from lifting heavy materials to precision work and material manipulation.[202]
Definition
ISO defines nowadays industrial robots as :

"automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications".[203]

In construction, the tool is used to automate processes like pick and place, but also to construct structures as seen in bricklaying, wall extrusion and and the creation of spacial forms. These tools often integrate sensors to enable complete autonomy.[204] The tasks can be divided into 3 groups: addition (pick and place), subtraction (cnc) and deformation (bending and forming).[205]



200. Wallén, 2008, p.9
201. Wallén, 2008, p.10
202. Misiti, 2020
203. IFR, 2023, p.29
204. Parascho, 2022, p.186
205. Parascho, 2022, p.186

Robots in Wood Manufactures

In 2017, IRF measures that wood production, which encompasses manufacturing of wood for construction, furniture and cork,[206] has only 0.2% of all industrial robots making it one of the less interested sectors.[207]

In “Opportunities for robotic automation in wood product industries: The supplier and system integrators´ perspective”,[208] Landscheidt et al. tried to understand the desinterest. They interviewed 5 different wood manufacturing companies in Sweden. Their findings highlighted several notable factors contributing to the wood industry’s delayed adoption of automation, and concerns that the irregularities of raw wood might make it difficult to meet robotic system standards.[209]

Introducing robots would imply a better control of the quality and the regularity of the wood between sawmills and constructors. Some industries see, however, potential in increasing competitiveness, and making more positive work environments.[210]

According to the IFR, stocks for industrial wood robots have doubled since 2017. However, when examining the statistics for each region, Europe around 4000 stocks, while China witnessed a significant increase from 1115 to 4784 stocks.[211] This means that the visible increase just reflected China’s entry to the field of robotic manufacturing.

Robot Operator

Supposedly, automated machines like robots steal jobs from workers.[212] The Industrial Revolution has however already automated most of the labor and artificial intelligence doesn’t have enough capacity to surpass it.[213]
In the scale of the single worker, automation might lead to unemployment, but on the bigger scale, robots bring new technological development which creates jobs in other areas.[214] Thus, robot manufacturing doesn’t need workers to make repetitive actions, but rather more technical tasks for maintenance, which requires knowledge and skills.[215]
In the carpentry field, human workers need to be empowered and to be skilled.[216] Robots have greater quality in repetitive consistent tasks while humans are better for adapting and taking decisions.[217] As stated in Dégailler-Rochat et al. : *“It is only by giving control back to the worker on the shop floor that the full potential of new technologies can be leveraged to boost productivity, motivation and innovation”*.[218]

206. IFR, 2023, p.41
208. Landscheidt et al. 2017, p.233
209.-210. Landscheidt et al. 2017, p.238-239
211. IFR Statistical Department, 2023
212. Wallén, 2008, p.13-14
213. Dégallier-Rochat et al. 2022, p.2
214. Wallén, 2008, p.13-14
215. Landscheidt et al. 2017, p.233
216. Dégallier-Rochat et al. 2022, p.2
217. Parascho, 2022, p.191
218. Dégallier-Rochat et al. 2022, p.4

Conclusion

The introduction of machines has profoundly altered the impact of wood conversion from the 15th century until today. However, such transformation would not have been feasible without technological advancements in iron making, energy production, and transport.

Waste

The surge in productivity and the shift in forest management have profoundly altered the biodiversity of woodlands, diminishing their regeneration capacity.
Since the advent of sawmills, curved wood became unusable for wood construction.

Consequently, more diseases are emerging today, because they spread more easily in monocultral forests. Coupled with cutouts from lumbering, lamination, and CNC processes, the global production of wood waste has increased.

Distance

Since the 18th-19th century, new means of transport, coupled with the open market, have facilitated the global distribution of wood. Wood was made available even in countries that didn't have forest or where wood was too expensive.

The separation of processes from felling, to sawing and manufacturing has furthermore increased transport in the production.
As a consequence, CO2 emissions have increased from the Industrial Revolution till today.

Skills

Carpenters have lost their autonomy and skills, because of the introduction of factories and machines. Not only has the income of skilled workers decreased, but the weekly hours have increased. In nowadays industry, there is however a demonstration of how skills and human decision-making can be used to better understand the irregularity of wood.

The following chapter will focus on the current application of machines in the industry.

	Tool	Productivity m3/year		Waste	Transport	Skills
1500	Hand tool	90				
	Water-sawmill	900		no curve		
1600						
	Gang-saw	1800	standard	lumber		factories
1700			coke	coal		
	Steam-engine					
	Machine-Tools	3000				
	Circular Saw		interchange			
	Milling machine		nails		steam boats	
1800	Decoupier saw		steel sheets		open market	
	Jacquard mach.6500		2x4			
	Planning machine		balloon frame	laminate		
	Steam sawmill		dowels		trains	
	Ban Saw					scien. man.
1900	Copy Saw		waterproof			ford
	CNC		glulam	trim		contractors
	Robots		chipboard			strikes
	Carpentry machine		mdf			toyotism
			osb			
2000	Modern gang	27000				
	Chipper lines	630000				

Process

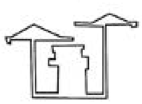
219.

 I. from Tree to Log

 II. from Log to Lumber

 III. from Lumber to Glulam

 IV. from Glulam to Framework

 V. from Framework to Building

The process chapter will focus on the construction of the wooden tower of Malley Phare, in Switzerland. The project is a demonstration of the massive production of glulam. Visits in representative enterprises will explain the different steps of the processing.

A visit to the Forester's office of Marc Rod in Ropraz will give insights on the Management and extraction forests in the canton of Vaud.
A visit to the Sawmill of "Scierie Zahnd" will delve into the conversion of wood logs to lumber.
A visit to factories of the JPF-ducret group will explain the conversion of lumber to glulam and the assembly of elements.
A visit to the construction site in Malley will explain the construction of a glulam tower.

219. Map made with Google Earth, 2023

I. from tree to log

The “Groupement forestier Broye Jorat” is a group of forest rangers working in the forests of the region of Jorat, in canton de Vaud, Switzerland. They are hired by the state, or by private owners to manage and take care of their woodlands. Marc Rod, an expert forest ranger, specializing in sorting, explains the processes involved frp, tree selection and felling within the Ropraz village and the surrounding Jorat region.

A. Inventory

There are two types of forests, which are forests for production and forests for leisure. The forest for production exploits trees for the sawmills and for energy. The forests for leisure are mostly saved for public use. Portions of these woodlands serve protective functions against natural hazards such as stone falls and water overflow.
An updated forest management plan, mandated by the state, details the species inventory with measured density, guiding the rangers in their ongoing efforts

B. Selection

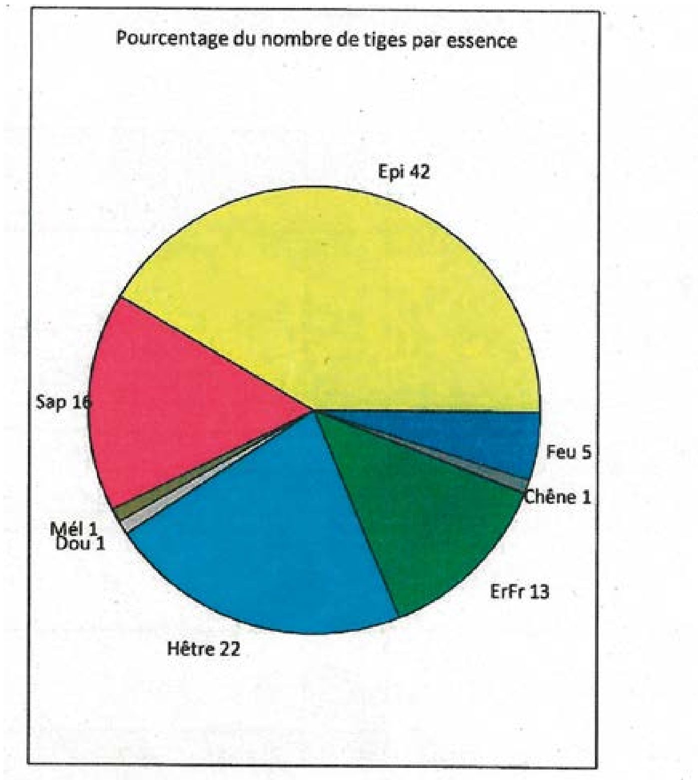
The forest rangers estimate the number of trees to fell in what region from the management plan. They select wood not to answer the market’s demands but to follow the forest’s needs.
The selection process involves targeted approaches: singling out specific trees, creating space between trees, forming clearings to improve the growth of young trees, and selectively felling larger areas, but only in specific cases. For example, considering the need for a Spruce tree to have 7 meters of free space for optimal growth, and an oak requiring 15 meters.

C. Marking

Once selected, the chosen trees are marked by the ranger. The subsequent decision regarding whether the tree will be destined for sawmills or energy production depends on factors such as demand of the market and the quality of the trunk.

D. Felling

Following marking, a skilled lumberjack employs machinery to fell the trees, trimming branches, and leaving the wood along the roadside. Subsequently, sawmill managers or energy producers purchase the harvested wood from the forest managers.



220. C297 COMMUNE DE ROPRAZ 2019
221. Map made with Google Earth, 2023

From Monoculture to Polyculture

Addressing historical forest development practices, the transition from monoculture to polyculture becomes imperative. Forests created in the 19th century with uniform height and species now face challenges due to their susceptibility to climate change. Woodlands made only of coniferous trees are less resistant to climate variations. Diversification with new species becomes essential to adapt to changing environmental conditions.

Bostryché

Spruce wood is one of the most used wood in the construction industry. It has been decimated for a few years because of an insect called bostiché.
The trees die quicker, and bruises appear on the surface.The construction industry doesn't want to use it in consequence. Wood infected with bostriche can however still find use in construction, albeit with the condition that it must be cut and utilized promptly. Despite the aesthetic concerns among architects, bostriche-infested spruce wood demonstrates structural qualities comparable to standard wood.

Heat

Wood, cut into smaller chips, undergoes natural drying in warehouses through a fermentation process. Subsequently, it is sent to energy centers or individual consumers in need.

Conclusion

Architects are encouraged to explore innovative uses for bostriche-infested wood. Planning for the utilization of wood resources must be strategic, considering the forest's needs rather than immediate market demands. While expeditions for urgent projects occur, the general practice emphasizes a thoughtful and sustainable approach. Pricing dynamics play a significant role, with industries often influencing wood selection. Foresters find it economically viable to redirect wood, especially when architects may reject irregularities for construction, favoring heat production instead.

II. from Log to Lumber

Scierie Zahnd in Ruyères is the second biggest sawmill in Switzerland. It converts around 170’ 000 m3 of wood logs to lumber per year. It transforms wood for the use of carpenters, packaging, heat and glulam industry like Jpf-Ducret which is one of its main clients. The sawmill is situated on a large site of 57 ‘000 m2 with different buildings and production sectors: Reception, Sorting, Sawmill, Storage, Drying Chambers, Optimisation, Energy and Machine Maintenance. Thierry Zahnd, co-owner and co-manager of the sawmill explained the different steps of from log to lumber.

A. Reception

Daily, 35-50 trucks bring logs ranging from 4 to 24 meters. The wood originates from the canton of Vaud (45-50%) and from other regions such as Neuchâtel, Jura, Bern, Fribourg, Valais, and a minor part is sourced from imports (4%). The sawmill mainly processes softwoods, with half spruce wood and half fir wood, which are the most used in construction.
An operator receives the wood and visually checks the quality. The operator picks up the arriving logs with a small crane and initiates the conveyor tray. If necessary, the log is rounded and debarked for easier manufacturing.

Norms

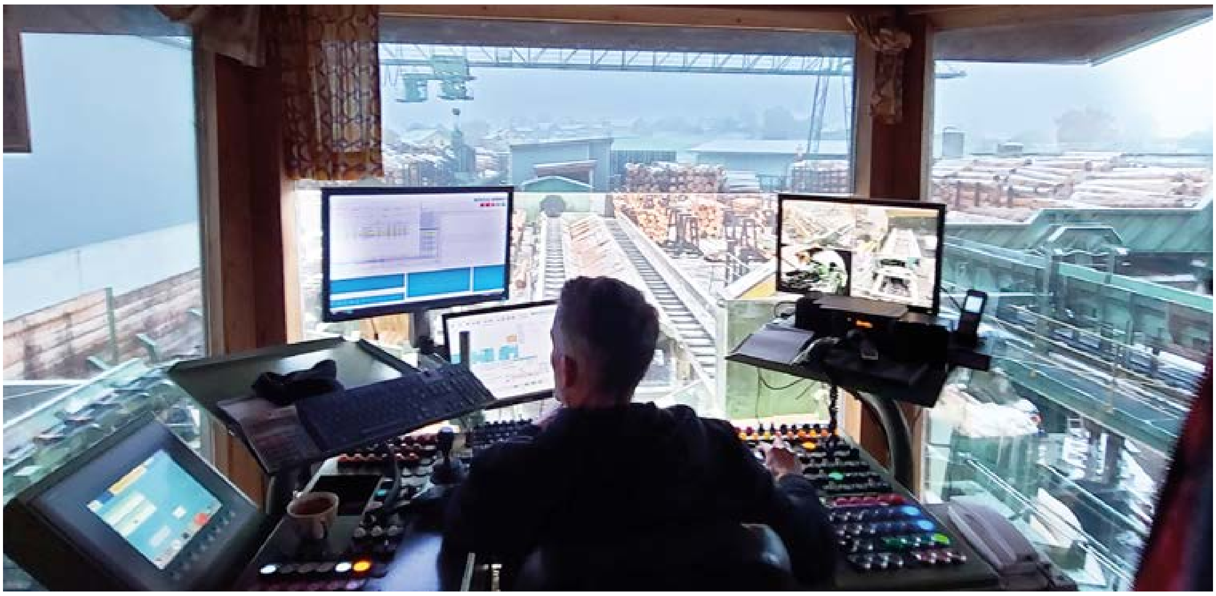
Swiss norms are strict regarding wood defects. For construction, purposes any signs of discoloration, woodworm infestation, diseases, cracks or large knots are not allowed, especially in the case of glulam. Wood that is still usable but doesn’t meet these strict criteria, is either used for packaging, pallets or energy. Alternatively, it may be exporte where the norms are easier.

Disease

Wood infected with bostryche infections is used for energy or other pruposes. Thierry Zahnd asserts that Swiss woodlands are not renewed enough and the construction industry might need to use other species if nothing is done.

B. Sorting

The log advances through the conveyor tray and stops at another operator. The worker sorts the wood according to 4 criterias: length, diameter, species, and quality. Special cameras permit visual control on the quality. As a consequence, sorting decisions are delegated to the autonomous operator.
The wood is then sent to different sorting boxes though the tray. In parallele an operator in a crane moves the stacks around for better storage disposal.



C. Sawmill

An operator manages most of the operations through the use of cameras. A lumbering division type is chosen depending on the purchase order. The logs are sent in the stack to avoid processing adjustments.

Squaring

The log is pushed through a double band saw that cuts two sides of the log. A rotator then turns the log 90° and another double band saw cuts the two other sides of the log making a squared timber. The squared timber is then laminated to make a perfect square section.
Lumbering
Depending on the chosen division, the log goes through consecutive gang saws turning the log into a stack of lumber

Optimisation

Large cutouts from the squaring are optimized by an operator to make usable lumber.
Sorting
2 to 3 standing operators check visually each plank and sort them by dimension, section and defects. Another group of workers, then, stacks up the planks with a stacking machine, inserting separating wooden sticks. Finally, stacks are sent to the external storage through forklifts.

D. Storage

Despite the large parcel surface, the sawmill doesn't have enough storage to respond to the growing demand for sawmilled wood. Thierry Zahnd is planning to increase the parcel size by around 50% next year. Raw wood is stored on the open field and dried wood is stored in protected warehouses. Importantly, stacks of undried wood always have separations to avoid rottening. Green Wood is exported because it is unusable in Switzerland.

E. Drying Chambers

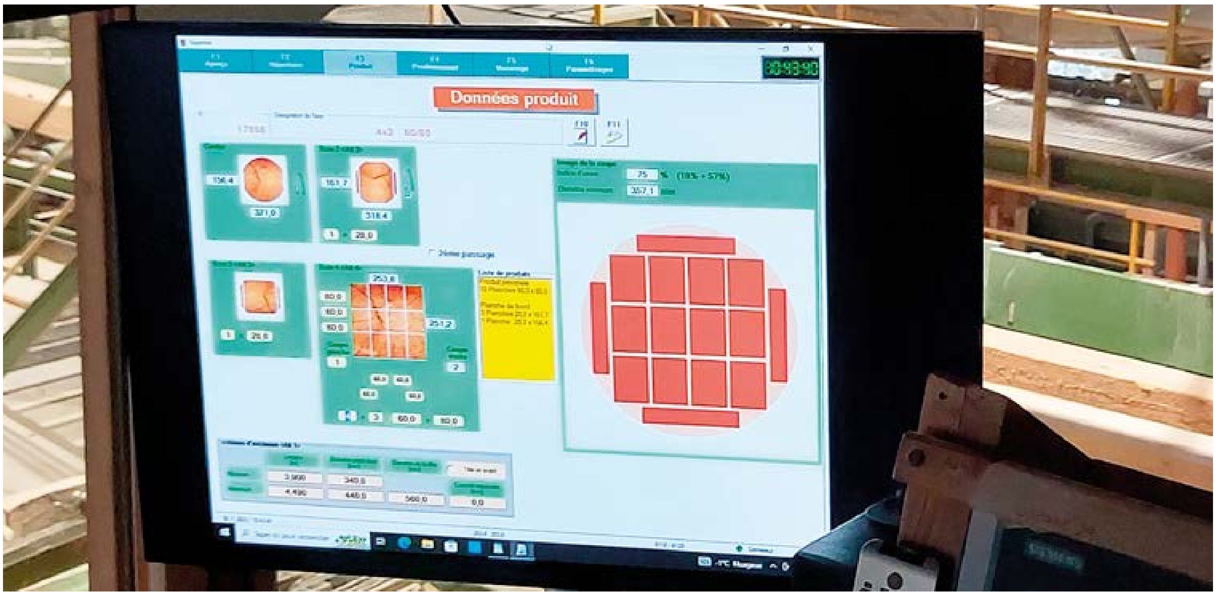
The sawmill has 5 drying chambers. Healthy wood is dried from 50% of moisture to 12-15% during 5 days. The moisture has to be precisely controlled, specifically for glulam. The heat is produced by burning wood waste. Wood is stacked with large separation sticks for better air diffusion.

F. Optimisation

A second sawmill specializes in repurposing defectuous lumber. Wood is sorted and cut into smaller sections.

G. Energy

A partner enterprise called Enerbois, which is situated at the same site, reuses the wood waste like bark, dust, cutout and sick wood for the production of energy. Thanks to that, the transport of wood waste is reduced.


Données produit

III. from Lumber to Glulam

JPF-ducret is a construction company based in Bulles, Switzerland. It has 3 fields of activities, civil engineering (JPF), wood construction (Ducret) and glue production (Renoantic). The wood construction unit specializes in the production of glulam and cross-laminated timber (CLT), producing around 13 '000 m3 per year.

They have 3 factories, one in Orges for manufacturing, one in Yverdon for slab and assembly and one in Le Pâquier for smaller frameworks. This chapter will focus on the glulam production in the factory of Orges. The main warehouse of Orges contains the steps :
Reception, Diagnosis, Corrections, Finger Joints, Lamination, Glueing, Storage, CNC and Assemblage.

A 3D model of each element is made, prior to the processing. It contains all the machining steps and the number of glued lumbers per piece. William Blanc, plant factory manager explains the steps from lumber to glulam.

A. Reception

Due to space restrictions, the wood is stored in the attic of the warehouse. Trucks arrive and unload in front of the reception. The material is then lifted with forklifts. The wood is sorted by orders in stacks.
In the production of glulam, various wood pieces with different densities and humidity are assembled together to create a composite material with balanced and consistent properties The gluing process works only if the wood has a hygrometric level of around 12-15%.

Swiss Wood

An average of 4 trucks per week drop 300 to 400 m3 of lumber. Wood orders consist of 95% Swiss spruce (Epicea) mainly from Scierie Zahnd SA, and others like Despond SA, and Olwo SA. The remaining 5% are Douglas fir from France and larch from Austria. For heavy load bearing-structures, hardwoods like beech are also converted into glulam, but they are more expensive and harder to machine. Spruce trees are generally favored because they are easier to work and dry, and normally don't deform a lot over time.
The glulam production follows the norm CE14080, ensuring traceability of every wood plank throughout the process.

Waste

From the received wood, 5% is discarded due to low quality. Around 35% is reduced through lamination. The waste is used for heating products or to heat the factory itself.

B. Diagnosis

Wood is sent to the conveyor tray downstairs. A first compartment equipped with X-ray and captors measures the density and the saturation level of each lumber, and they are consequently sorted into different stacks.


Elastan® TLP


Paul
X-RAY


MiCROTEC

C. Corrections

Lumber is dropped n a table at the end of the conveyor tray. An operator visually checks each plank for defects such as slits, nods and resin pockets. Chalk lines are drawn around the defect. The lumber is sent then to a machine which cuts it automatically.

D. Finger Joints

The lumber is conveyed to a machine that glues together planks to attain larger lengths. The drying time is around 25-30 minutes. The joint has been certified with a resistance 25% superior to natural wood.

E. Lamination

The glued lumber is conveyed to a laminating machine, reducing it by 35%.

F. Glueing

Workers pick the lumber, dip it in glue and stack them together on benches. Progressively, iron claws are set on each side with a hydraulic press to ensure proper gluing. A worker drops a weight on the top of each stack to maintain them aligned. The stack is then dried for 2,5 hours. To have efficient gluing sessions, many glulams are glued at the same time.
A large free space is used for glulam and a secondary smaller one for CLT. Ordinary glulam is made of lumber glued in one direction. CLT, is made of lumbers in opposite direction. The maximum respective side in the factory is 2x5m and 3x5m, CLT is stronger and has fewer humidity size variations. The process is however more complicated as it needs bi-directional clamps.

G. Storage

The glulam is then stored in an intermediary space. Each one has a label with dimension, species, traceability, name of client and date of production.

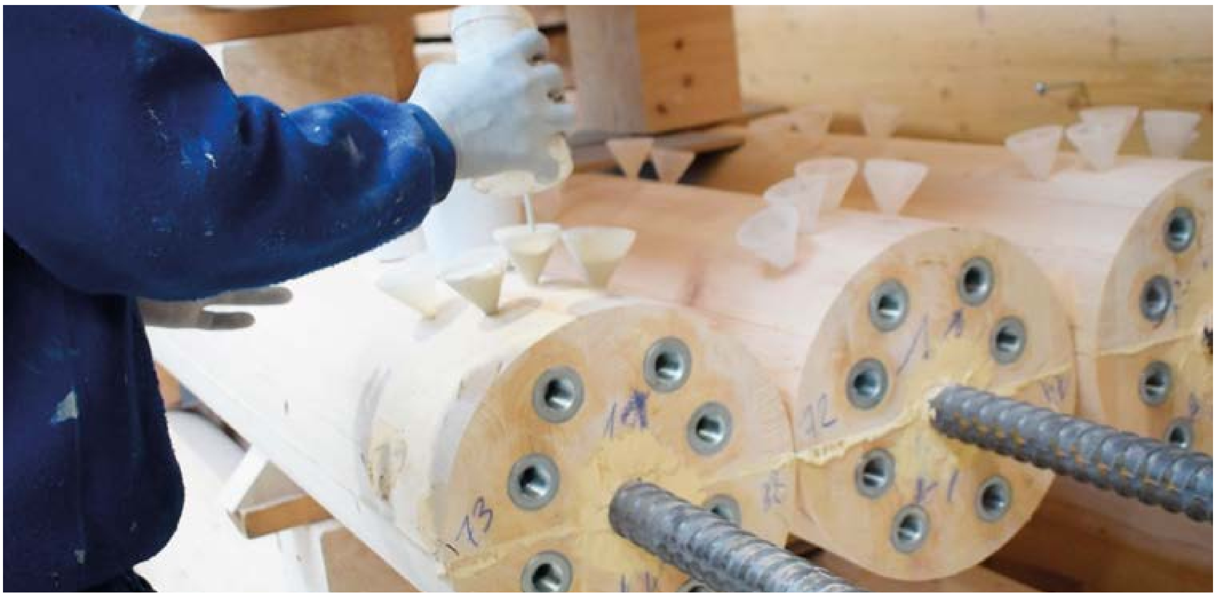
H. CNC

A glulam element is laid on benches. Dimensions are verified according to the received 3D model. An operator then signals the origin point and starts the process. All processing steps are programmed in the 3d model, so that the CNC can pick up its tools automatically from the machine center.
The process always starts with trimming all sides with a circular saw. The beam is then cut to its correct length. Milling bits and drills are finally used to make assembly details and joints.

I. Pre-Assembling

The elements are pre-assembled with steel threaded rods and glue, a technique alled “Ferwood”[222], originally patented by the group. It is then send to the the factory in Yverdon.

222. JPF-ducret, 2023c



IV. from Glulam to Framework

The JPF-Ducret factory in Yverdon is specializes in assembling wood frameworks and slabs from pieces made in Orges.
It’s a large open workshop warehouse with four spaces used for different purposes. At the time of the visit, elements were produced for the construction site in Malley: Preparation, Slabs, Finishing, Assembling.
They used beech wood for the framework and applied a hybrid approach that combined wood and concrete for the slabs, because of the complexity of the project.
Jean-Marc Ducret, Managing Director of the construction company JPF-Ducret SA explains the different steps from glulam to framework.

A. Preparation

Workers prepare timber elements with “Ferwood” assemblage.

B. Slabs

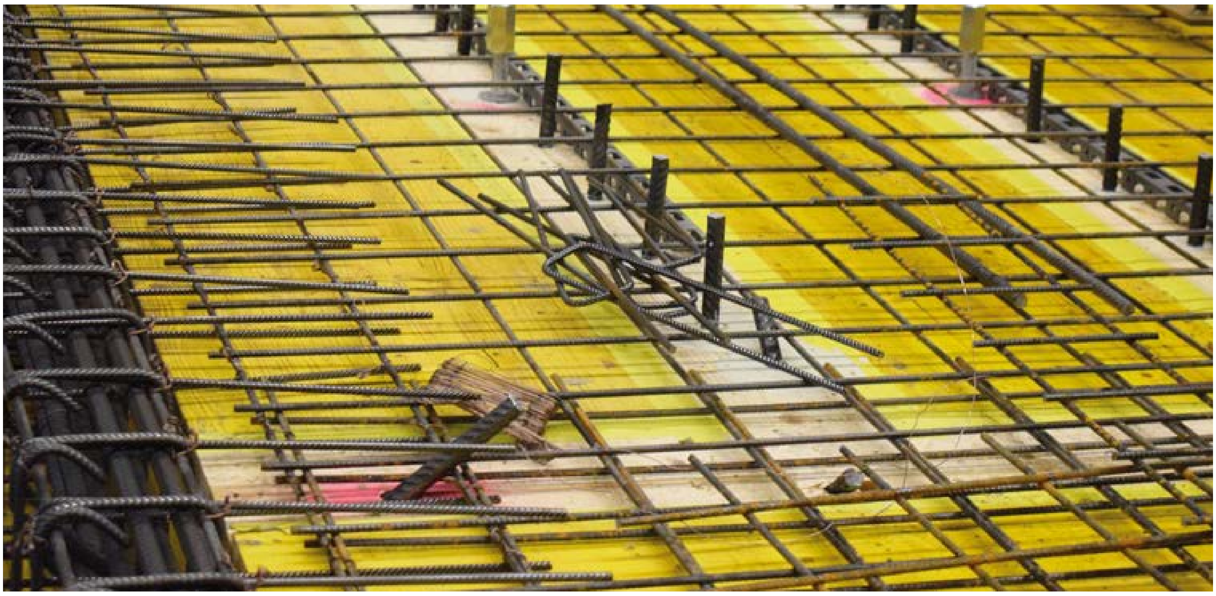
Wooden beams with iron threads are placed on the floor and casting planks are placed in between. Armatures are mounted on top, followed by concrete.
It’s in fact a hybrid between wood and concrete. A slab made entirely of wood would have been too large, weak to fire and with acoustic problems. A concrete slab alone would not only have polluted more, but would have also introduced too much weight on the hanging structure. This challenging project shows how no single material is a universal solution.
The prefabricated slabs are then stored outside and delivered by trucks.

C. Finishing

Glulam elements are corrected and finished by hand with a sanding machine. Some smaller slabs are cast aside.

D. Assembling

Glulam elements are assembled together and covered with fireproof plaques.
Assemblage
A couple of workers assemble a truss structure that forms the framework of the whole tower. The trusses will hold alternating floors like Vierendeel Bridge structures. Hardwood (Beech wood), is used for the horizontal parts to resist the larger traction and compression efforts. Softwood (Spruce), is used for the triangulation of the truss to better resist the torsion efforts.
Elements are assembled with “Ferwood” joints and dried for 3-4 hours.
Each truss is different because each floor has different housing typologies.
Protection
Groups of workers cover with fireproof plaques because the structure will stand inside the building.The trusses are finally mounted and leaned against the wall with straps and sticks.



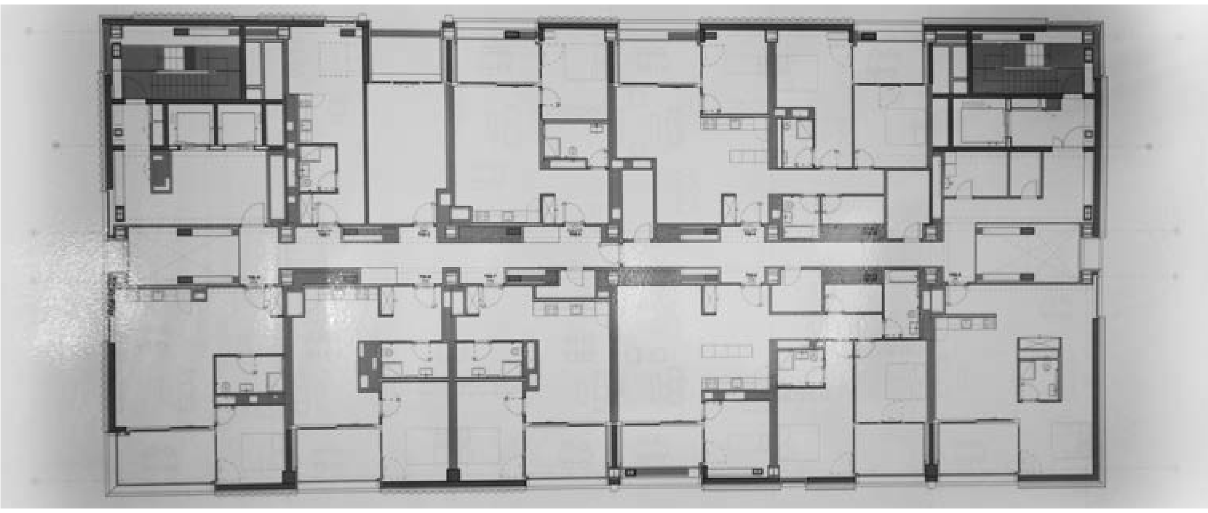
V. from Framework to Building

Malley Phare is a 14-floor housing tower on the Centre Malley Lumière, in Switzerland, being constructed by JPF-Ducret. *(n°3 page 106, left)*
Despite being called a tower of wood, the complex structural challenges demonstrate the limitations as well as the possibilities that lay in each construction material.
The massive construction involved Building Information Modelling (BIM) for optimal coordination of elements and participants. The involvement of architects was however difficult because the decisions were too isolated from the engineers point of view.
The project of Tilia Tower, also in Malley by JPF-Ducret, will serve as a comparative opposite approach.

Structural System

The building of Malley can be categorized as a tower in terms of its typology, but structurally it is a bridge. Like a trampoline, the building is hung on top of the existing “Centre Malley Lumière”. It was decided not to put weight directly on the existing structure, but rather to support i from the ground. The tower stands on U shaped concrete wall surroundsing the exisiting.
46 meters long steel beams, manufactured by the external enterprise “Sottas”, are hung on the walls with. The 14 floored tower is built on top.
Wood trusses measuring the width of the building are installed on alternative floors. The other floors have free plans.
Steel pull beams are finally spread behind the facade to solidify the whole building. Dimensions of all elements were carried out by engineers of JPF-ducret.

223. Photo of renders for Malley Phare and Tilia, CCHE, Itten+Brechbühl
224.-225. Photo of plans from Malley Phare, CCHE

224.


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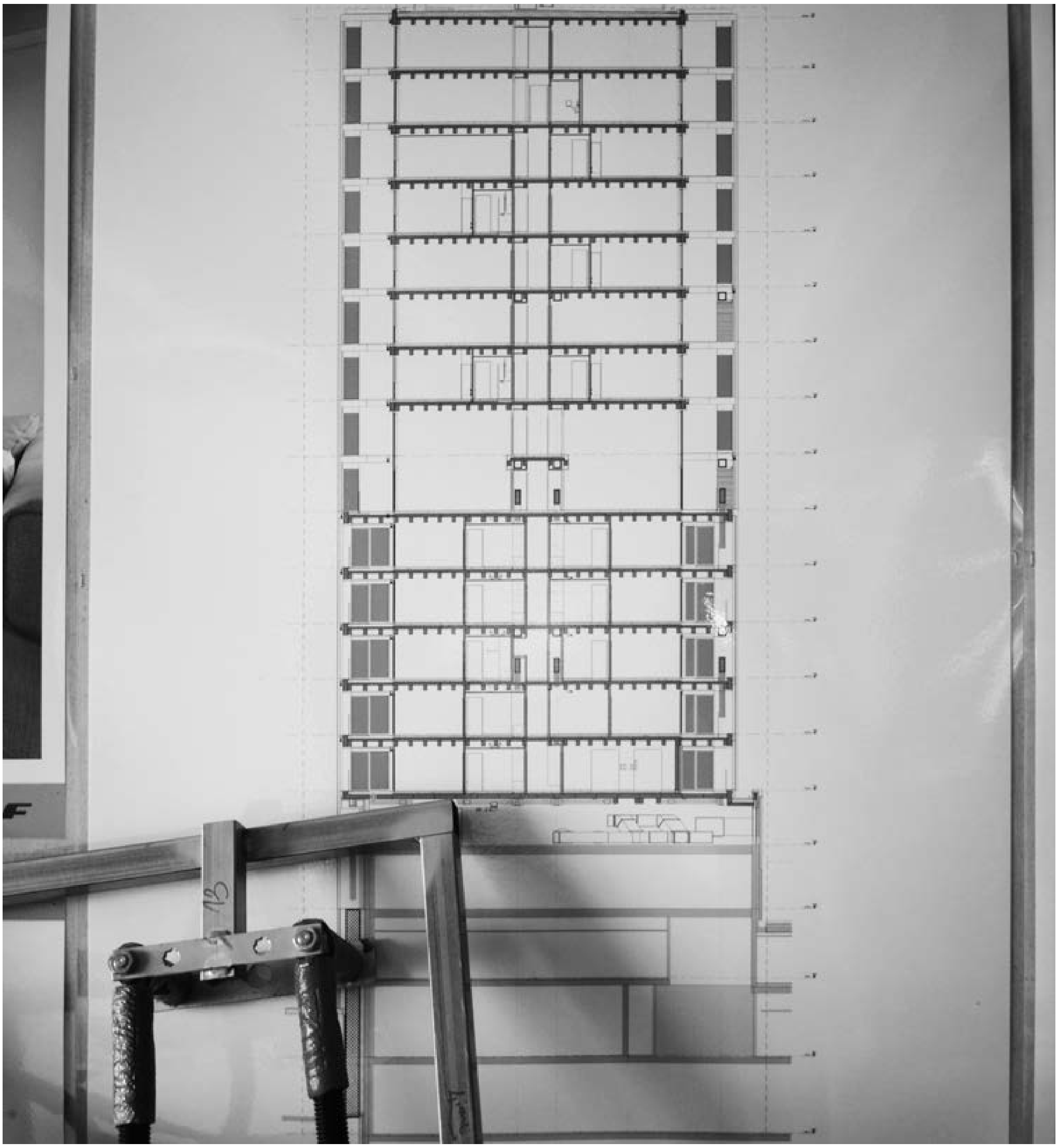

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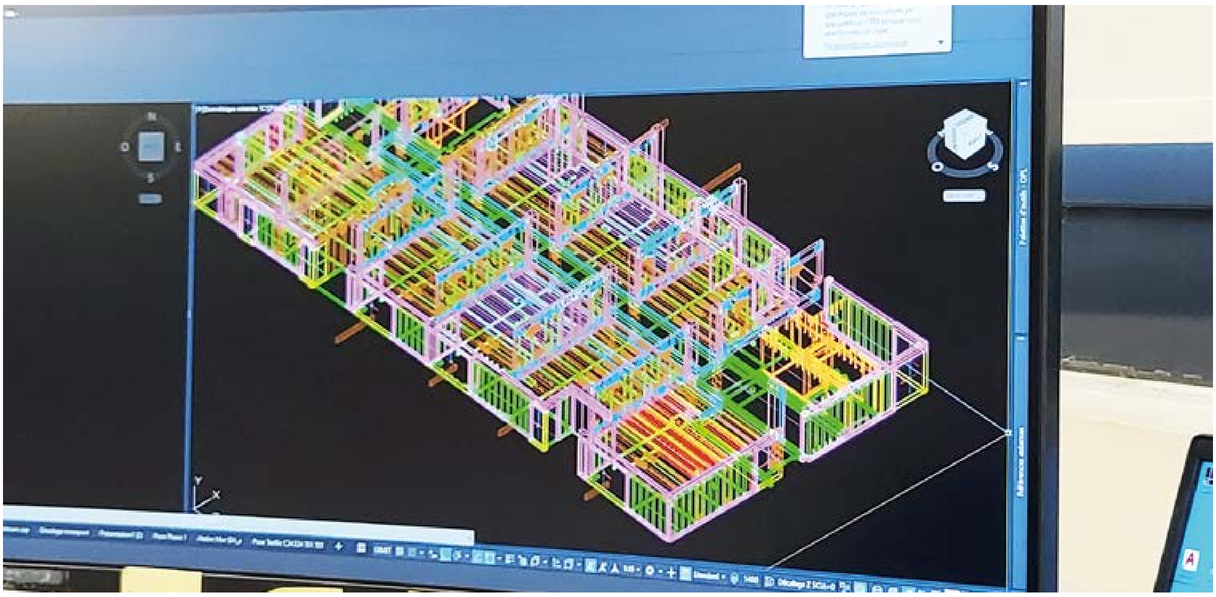


Not an all Purpose Material

A total of 750 tonnes of steel elements were produced for the tower. It might sound like a lot of steel but a fully wooden tower wouldn't have been possible to erect with the known challenges. The 24 floor Tilia tower for instance *(n°3 page 106, right)* which is also built by JPF-ducret in Malley, doesn't have that high quantity of steel. A large concrete core was, however, needed for stability and fire escape.
In both cases the application of unsustainable material results unavoidable. It has, however, a positive global impact because both were used with 60% wood in total.
The same goes for the hybrid slabs which were previously discussed.

BIM

Olivier Plantevin, BIM technician and coordinator in the Malley project, explains that because of its high complexity, the project was entirely drawn in a "Building Information Model".
It's a 3D model that includes and coordinates all the parts of the building. Information about the material and processing is integrated in each geometry. All floors are different and each element has to be modeled differently. Plantevin progressively sends each geometry to another technician who adds cutting, drilling and milling operations and sends them for CNC processing.

Construction Company vs Architects

In such large projects, architects' decisions are detached from construction.
On one hand, in Tilia, architects didn't get involved in the construction decisions. They focused on planing and producing images.
On the other hand, in Malley Phare, architects involved themself too much in construction decisions, but without participating in the BIM. As a consequence, the construction challenges and possibilities weren't fully integrated. Modeling the openings on an earlier step would have helped better to plan the trusses. The floors have for instance different apartment types. The wooden trusses must be accordingly adapted to insert openings and exceptions have to be done everywhere.

226. Photo of BIM for Malley Phare, JPF-ducret

Conclusion

Industrial production of wood has incomparable productivity compared to green wood squaring. It responds to a growing demand for wood and it elevates the material to a structural potential comparable to steel and concrete.
As shown in the projects of Malley Phare and Tilia, each material has potential and limitations. Adapted task need to be defined for each one.
The consequences of mass production need to be however attributed.

Sustainability

Jean-Marc Ducret states that using wood in construction is anyways a bonus in sustainability compared to other materials. Wood is a carbon absorber, and its use for construction contributes in any form to reduce emissions.
Sawmills and Glulam factories need however wood that doesn't have defects and is straight. The different steps of processing produce wood waste, from the rejection of defectuous wood logs to the generation of cutout and sawdust. Using the waste for heat doesn't solve the problem because it releases CO2 that could have been stored in construction. Augmenting the quantity of wood used per log might be more sustainable.

Disease

Because of global warming weakening woodlands, diseases like bostriche are becoming a problem. In woodlands used in monoculture of Spruce or pine, the infection is spreading like wildfire. Sawmill wood price is rising as a consequence.
Rapport of the OFEV, "Annuaire La forêt et le bois 2022", states that the price of Sawmilled wood increased of 25% from 2021 to 2022. [227].

Swiss Wood

Jpf-Ducret uses 95% Swiss wood because they sell high-value products, with high resistance and low deformations. Small carpenters have to use in contrast, foreign wood. The material is however constantly internally transported between sawmills and factories. Not only does distance affect CO2 emissions but it augments the infections of felled trees. Working closer to extraction site could reduce emissions and prices.

Despite workers' reduced involvement in the Industrial Revolution, sawmills like Zahnd, show possibilities of leveraging workers' visual capacity to augment productivity. However, the workers capacity to make has also advantages as was explained in the Hand chapter.
Finally, the lack of involvement of the architect's office showed how construction decisions taken in distance for project decisions can lead to complicated production. Architects should not only participate in decision-making but also be actively engaged in the modeling phase of construction to ensure smoother and more effective project execution.

228. OFEV, 2022, p. 83-84

	Steps	Tools	Workers	Waste
from Tree to Log				
from Log to Lumber	Reception	crane	1 operator	selection
	Sorting		1 operator	cutout
	Sawmill	band saw	1 operator	
	Sortage	crane	2-3 workers	
	Dryer		2-3 workers	
	Optimisation		2-3 workers	
	Energy		2-3 workers	
	Maintenance		2-3 workers	
from Lumber to Glulam	Reception		2-3 workers	
	Diagnosis	x-ray		selection 5%
	Corrections	mach-saw	1 operator	cutout 1%
	Finger joint	join maker		sawdust
	Lamination	planner		cutout 35%
	Glueing	press	2-3 workers	
	Storage		2-3 workers	
	CNC	cnc	1 worker	trim 5%
	Pre-Assembling		2-3 workers	
from Glulam to Framework	Preparation		2-3 workers	
	Slabs		5-10 workers	
	Finishing		2-3 workers	sawdust
	Assembling		5-10 workers	
from Framework to Building				

Tools Juxtaposition

Proposed Process

What happens when Information is introduced in Wood processing?

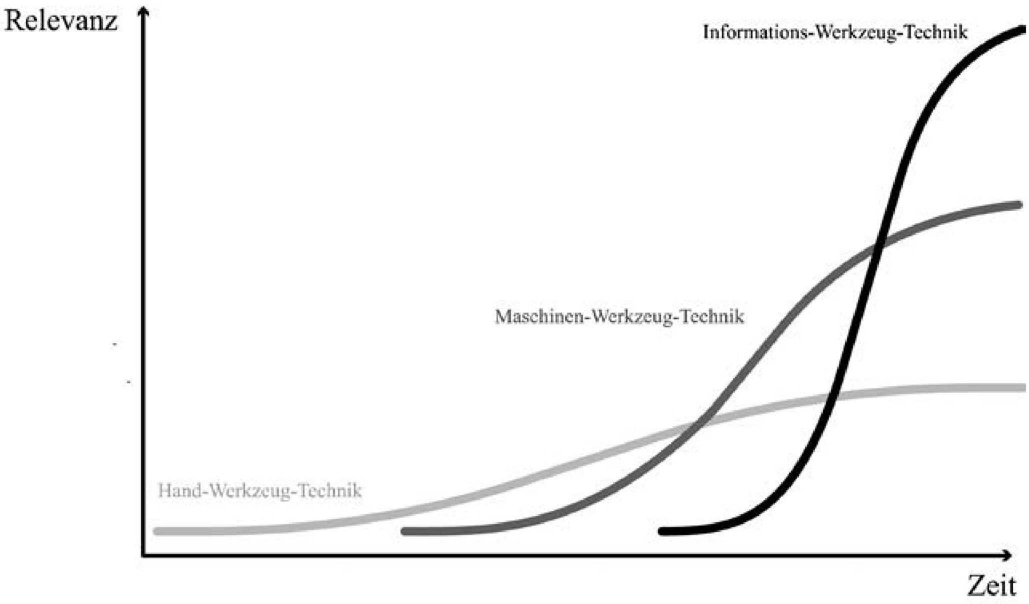
In today's industry, the utilization of information in the wood processing is only in its embryonic state. The proposed solution entails the coordination of information, machine, and hand tools in the wood conversion process to mitigate the impact of transport and waste while fostering autonomy and skills.

In a fist step, the "Hand" and "Machine and Hand" chapters will be compared to evaluate their potential and limits.

A proposed process will be presented in response to current challenges, drawing on actual examples of research in the field.

Tools Juxtaposition

229.



I. II. III. IV. V. VI. VII. VIII.

I. Ax

II. Joint Tool

III. Single-Bevel Ax

IV. Saw

V. Sawmills and Machine tools

VI. Machine hand tools

VII. CNC

VIII. Robots

229. Image taken from Schindler, 2009, p.88

Hand **Tools**

Overall, the hand tools have a flexibility that permits working in any place and adapting to any kind of wood shapes. Both the skills and the autonomy of the worker are promoted.

Ax

The ax is specifically adapted to deal with curved and irregular wood. Fibers are also more respected than with other tools, which helps durability, water and structural resistance. Using an ax on green wood allows easy manufacturing of hardwoods.

Joint Tool

Making joints with chisels results is complicated and fastidious for the carpenter. However, it can be used for easier corrections and to create cavities in the joints. Deformations can be absorbed by the connection.

Single-Bevel Ax

Single-Bevel axes have larger wedges and thinner blades. They can adapt less to curvatures and fibers are less respected. However, the finishing is more uniform.

Saw

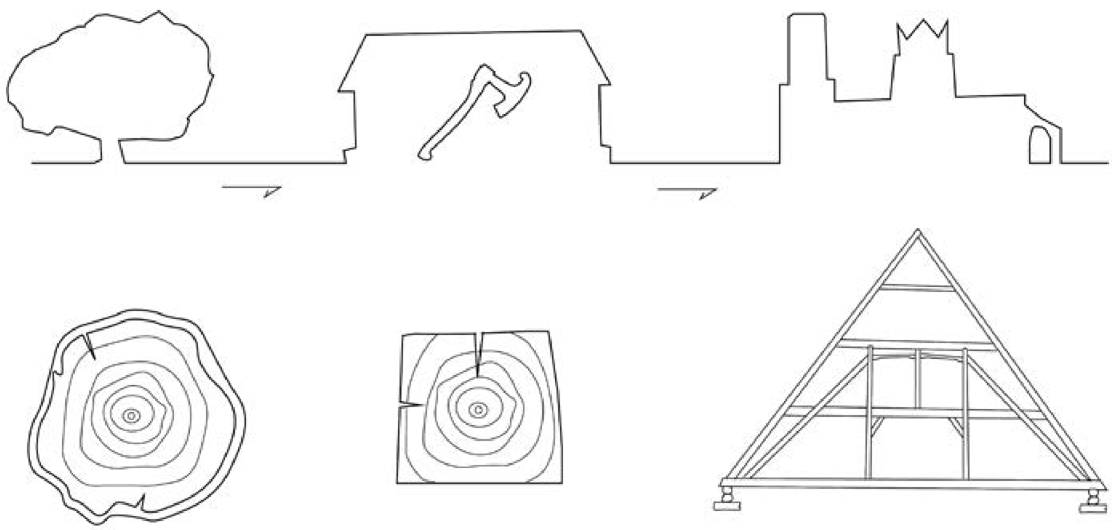
Saws are less adapted to curvature and fiber directions. It can be however used for fast joint making and corrections of timber lengths.

Machine hand tools

Drills, and mortise machines can be used to make joints easier and faster. It can then be corrected and adapted with chisels. Chainsaw helps when dealing with very large log sections to start wood squaring. It can also be used for the notches preliminary to squaring.

Hand **Process**

Steps					
	Selection		Tool	Enhancement	Wood
	Squaring				
		Tracing	plumb line		log
		Nicking	ax	chainsaw	
		Smashing	ax	chainsaw	squared
		Finishing	ax (single-bevel)		trimmed
	"Épure"				
		Tracing	plumb line		
		"Mise sur ligne"			
		Joint	chisel	mortise machine	notched
		Assembling			
(2 logs / day)					



Hand **Process**

The “Atelier de la Grande Oye” has shown the potential and the limits of hand tools. Here are statements to take into account when squaring in the contemporary era.

Less is More

The projects with a smaller scale and a reduced complexity have proven to be more sustainable in the global scope. Despite the simplicity and reduced processing of wood squaring, the project of Notre Dame implied complex logistics.

Stay Competitive

The “Atelier de la Grande Oye” has demonstrated the possibility of staying competitive in the industrial paradigm. The use of curved wood, and the reduction of energy and transport have permitted to reach comparable prices to industrially produced wood.
However, the performance came with a drawback, as capital gain needed to be added, and the salary of the carpenters was reduced.

One Space

Despite the complexity of their site, characterized by hills, rivers and bridges, they have shown the possibility of encapsulating wood conversion in a single space. This was allowed by the use of hand tools and of simplicity of the operations.
In consequence, no transport was needed between steps.

Local and Seasonal Wood

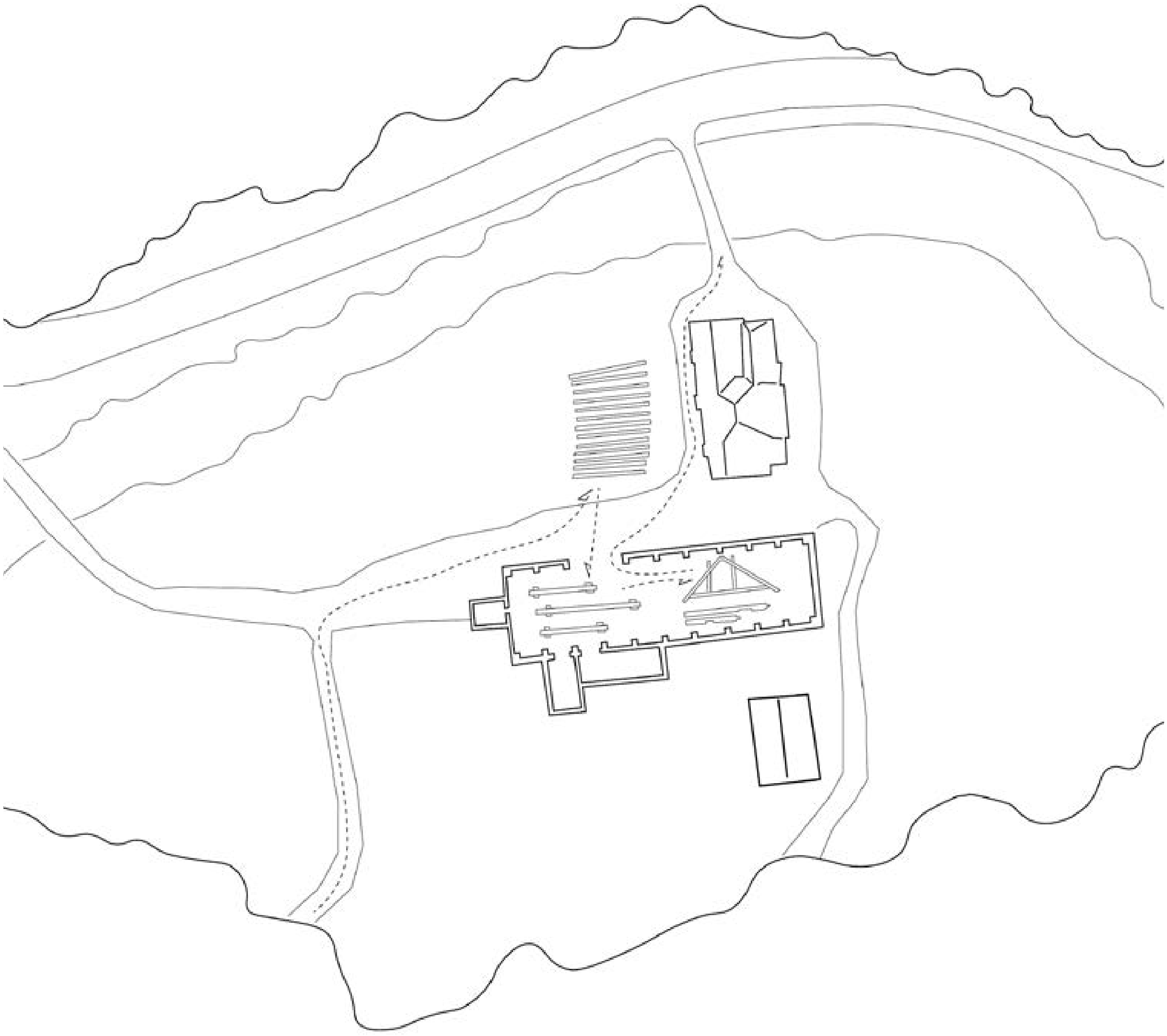
As demonstrated with Notre Dame, bringing wood from far unrelated places makes wood more vulnerable to infections. Hence, wood is brought from local forest (5km radius) for most of their projects. They are harvested in the winter season when the log is less heavy and less prone to infections. For that reason, wood is less sick and less transport is needed.

Pre Planned Purpose

Imagining the use of a tree before felling it, is advantageous to reduce waste and price. In fact, the projects integrate curvatures and irregularities in their design.

Hand and Machines

Machines can be used pragmatically to reduce time and efforts of some steps of the process.



They have a productivity much higher than hand tools. However, the sole use of machines provokes more waste and transportation. Most of the worker's job is maintenance and activation of the instrument.

Sawmills and Machine Tools

Sawmills can't adapt to curved or irregular trunks. Through lumbering it produces more cutout and wood dust. Because of its fixed situation, most of the sawmills imply transport.

CNC

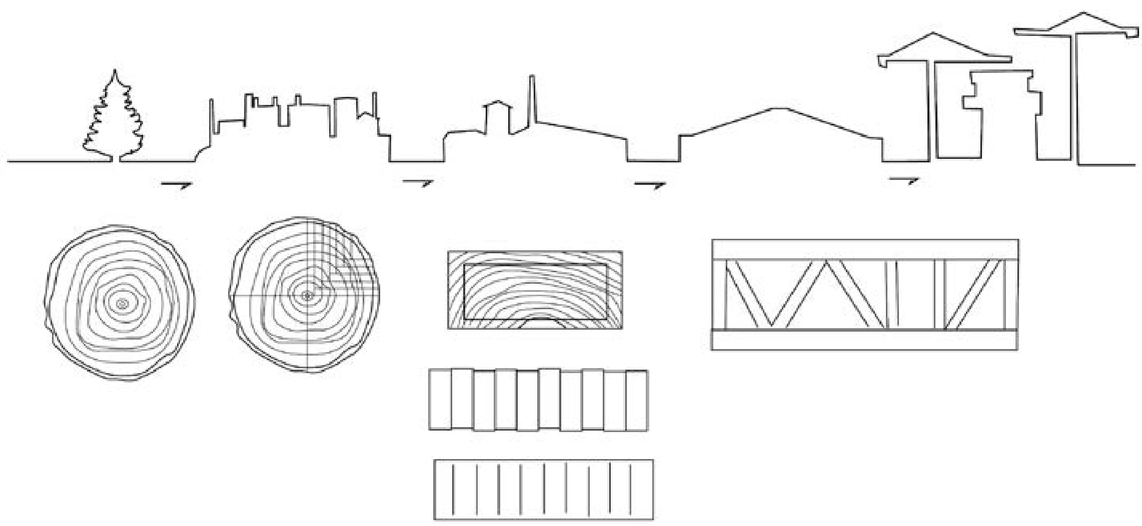
Numerically controlled machines could integrate any form of the material. The operation of the machine works with tools like, milling bits, drills, saws. However, it needs complete modelisation of the element and can't deal with unpredictability. In consequence, processing of complicated logs can lead to inefficient processing.

Robots

Arguments made for the CNC also apply to robots. However, the multiple axes and the possibility to insert visual communication, make them more adaptable to precise processing tasks.

Machine Process

	worker	wood	machine
from Tree to Leg			
from Log to Lumber			[170’000m2/year]
Reception	visual control	log	35-40 trucks a day
Sorting	visual control	debarked	small crane
Sawmill	visual control	lumbered	machine saws
Storage			
Drying Chamber		dried	drying chamber
from Lumber to Glulam			[130’000m2/year]
Reception		lumber	7 trucks a week
Diagnosis			
Corrections	visual control	corrected	circular saw
Finger Joints		cut and jointed	joint machine
Lamination		laminated	machine planner
Glueing	hand work	glued	hydraulic press
Storage			gantry
CNC		trimmed	cnc
Pre-Assembling	hand work	pre-assembled	
from Glulam to Framework			
Preparation	hand work	pre-assembled	
Slabs	hand work		
Finished	hand work	finished	
Assembling	hand work	assembled	
from Framework to Building			



Machine Process

Visits in Scierie-Zahnd and JPF-ducret’s factories have shown the potential and the limits of the machine tools and the mass production industry. Here are statements to take into account when processing in the industrial market.

Sicknesses

As shown by the visit in Scierie-Zahnd, climate change and Bostriche infections are ravaging Spruce woodlands.
Sawmilled wood prices are rising and more logs are wasted. Thierry Zahnd advocates for more efficient renewing of woodlands to eradicate the disease.

Swiss Wood

Because of the high price of Swiss wood, only main enterprises like JPF-Ducret use 95% indigenous wood. Meanwhile, smaller carpentry firms have to use imported sawmilled wood for its lower price.
Thus, to be competitive in the industrial landscape and use local wood it is essential to add capital gain on the produced construction element. “Atelier de la Grande Oye” for instance, adds surplus for the artisanal and esthetical quality of their products.

Not all Purpose

The project of Malley exposed how materials have limits and qualities to take into account. In consequence, wood cannot be used for all purposes. However, it can be used to replace materials in places where it has the best purpose to make more sustainable buildings.

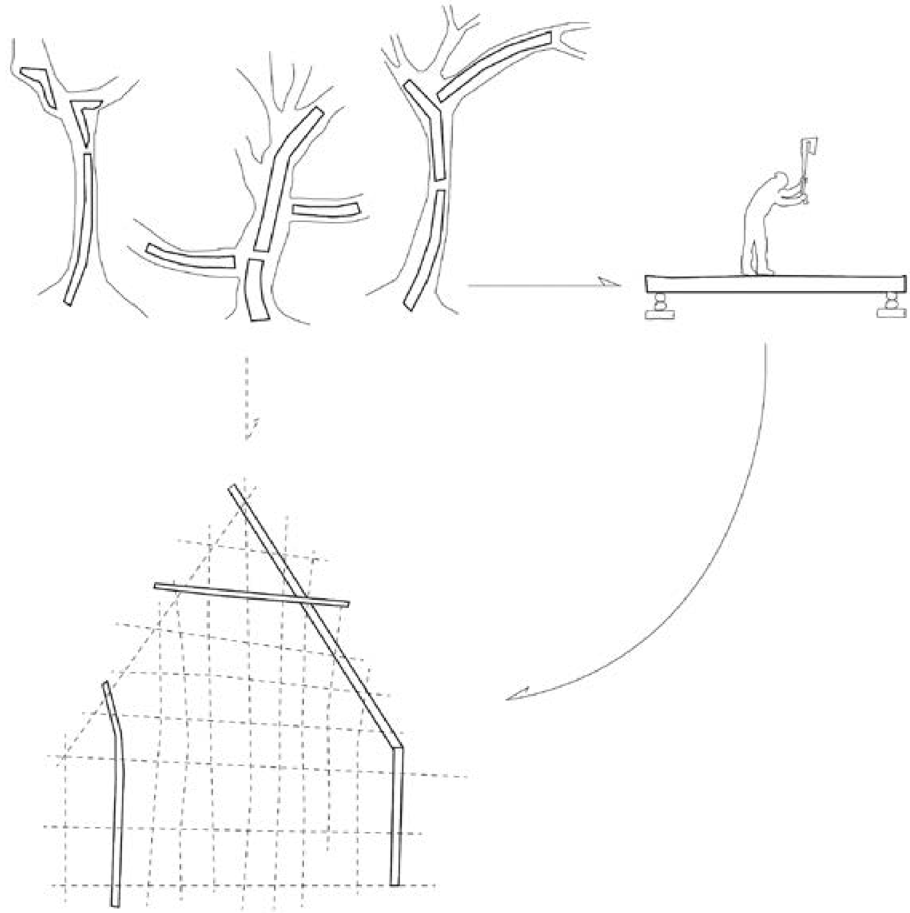
Worker Autonomy

Scierie Zahnd has demonstrated how human workers’ skills and autonomy can make a more efficient process. Since wood is an irregular and unpredictable material, human adaptability is the best suited to manage and control the material.

Architect vs Construction Company

Finally, architects have to involve themselves more in the modeling and construction process. Many opportunities lay in the industry, and integrating it could enhance sustainability, rentability and quality of built spaces.

Proposed Process



I.Selection II. Squaring
Analyse→Fell→Scan→Nick→Smash→Finish
III. |
“Épure”Trace
|
Place
|
Joint
|
Assemble

The proposed process aims to integrate hand tools, machines, and information to achieve competitive efficiency and optimize factors of distance, waste, and skills. Drawing inspiration from the green wood squaring process and incorporating insights from contemporary research, the following objectives outline what the proposal aims to attain.

Objectives

The final chapter seeks to empower workers and architects by introducing a wood conversion process that emphasizes viability and sustainability. The project is specifically designed to address the three primary challenges highlighted in the introduction: waste, distance, and skills.

Waste: Bottom-up

To reduce waste, the proposed process emphasizes a bottom-up strategy that enhances the utilization of curved wood. This not only minimizes material wastage but also fosters more complex and healthier ecosystems of woodlands.
The proposal will further respect the traditional seasonal cycle of wood squaring. Extraction in winter ensures lighter and less infection-prone logs, facilitating a sequential wood squaring process.

Distance: On Site

Addressing the transportation aspect, the proposed solution advocates for an on-site approach to wood conversion. Wood processing should occur directly in extraction areas or their nearest neighborhoods, consolidating all steps within a single space.

Skills: Ax

The emphasis is on hand tools, particularly the axe, as it can leverage the abilities of humans. With an ax, the workers is capable of cleaving curved, irregular shapes unsuitable for conventional sawmills.

The "Atelier de la Grande Oye" has demonstrated the potential of machines to enhance handwork approaches in specific tasks. The proposal advocates for a synergy between traditional hand tools and modern machinery. It will explores how hand tools can effectively utilize wasted wood on site while maintaining competitiveness with machines.

Humans and machines possess distinct qualities.

Humans for Adaptability and Decision Making

Artisan's work has demonstrated a valuable adaptability to wood processing. Firstly, axes enable the working of logs with curved shapes. Secondly, humans can move and twist irregular wood to fit it into joints.
Both advantages are crucial to combine with the materiality of green wood because its ductility makes carving and bending easier. Consequently, green wood and axes serve as the lever to empower human labor.

Machines for Precise Consistent Actions

Some tasks are very tiring and repetitive to do by hand, such as the initial steps of wood squaring and joint making. Both tasks put the worker in an uncomfortable position to work in a monotonous manner.
Robots, on the other hand, are very efficient in performing precise and repetitive tasks without experiencing fatigue. They are also helpful for handling heavy elements and positioning them precisely in space. However, these advantages rely on the robot's capacity to receive feedback. One approach is to implement visual response, while the other is to provide guidance through human input.

Human-Robot Collaboration

Carving irregular elements, and fitting them together is more adapted to humans, repetitive cutting and load bearing is more adapted to robots. Since both are used simultaneously in wood squaring, both entities could work together in assembling frameworks.

I. Selection: from tree to log

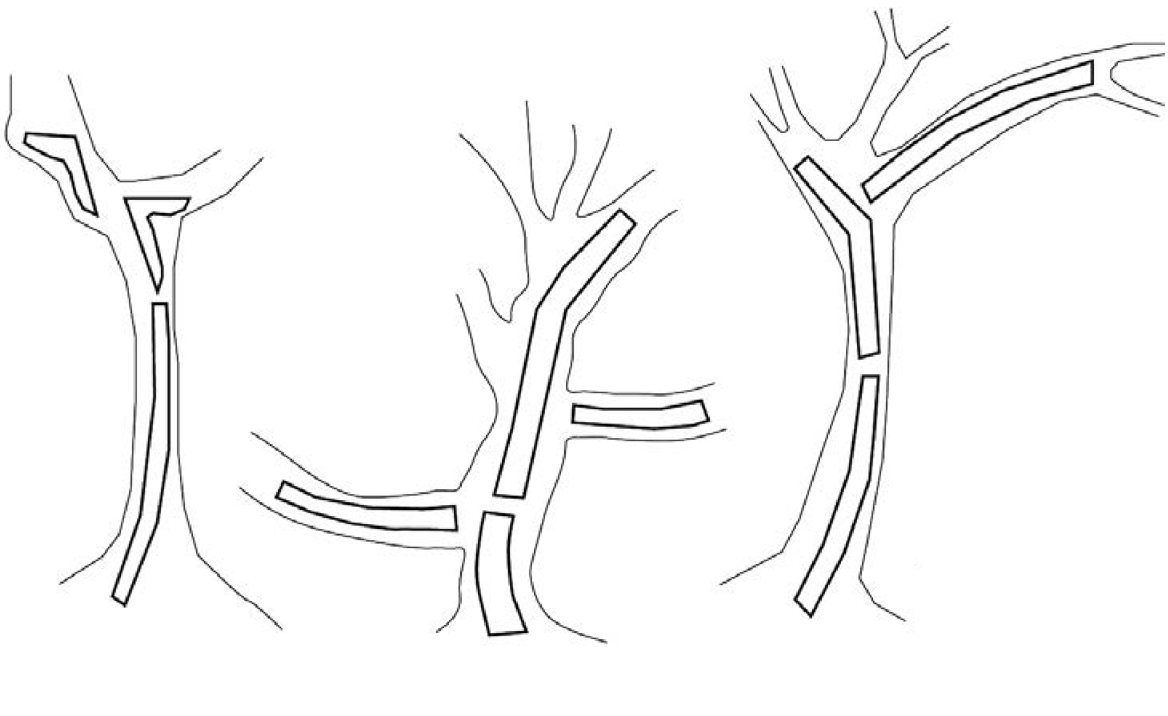
The initial step in the production process is the selection of trees, crucial for defining their use and reducing stored wood and waste. The proposed step includes:

A. Analysis and Integrate
B. Fell

Selection is optimized during winter when trees have lower sap content, predicting the wood needed for the entire year. Adopting a bottom-up approach involves utilizing various shapes and wood species. Trunk curvature and irregularities serve as project vectors instead of constraints, with the structural logic of branch disposition integrated into the design.

Learning from Medieval Boat-Making

Historical practices until the 19th century involved using both straight and crooked logs for shipbuilding, showcasing the adaptability of irregular wood. Straight long oaks were used for planking, curved oak logs, for structural reinforcement,[233] *and buttress roots for boards.*[234]
This technique found applications in Viking ancestral housing, German Fachbau facades (page 122 top), and English Cruck farms (page 122 bottom), which utilized wood curvature for expansive structures without intermediary supports.[235]



230.

230. Image inspired from Schindler, 2009, p.104
231. Image taken from Schindler, 2009, p.104
232. Image taken from The-past, 2019
233. Schindler, 2009, p.96
234. Miller, 2000, p.19
235. Larsen, 2022, p.495

231. 

232. 

A. Analyse

To find a potential use for a chosen log, a geometrical and structural analysis of the tree should be driven. A skilled carpenter would be able to find a purpose just by looking. However, various methods exist to enhance the analysis.

Hypothesis 1: Orthophoto

Diverse wood species exhibit varying structural strength and deformation characteristics.
An illustrative example can be observed at Scierie-Zahnd, where workers undergo training to visually identify wood species. This visual control method extends to evaluating wood quality and identifying potential diseases. According to Thierry Zahnd, relying on the human eye remains the most accurate approach for diagnosing natural and unpredictable materials. This practice not only enhances the skills and autonomy of workers but also ensures the efficiency of the wood processing procedure.
A comparable strategy can be applied through a simple orthophoto. An artisan can employ the image to deduce timber elements from a tree in a more pragmatic and straightforward manner. The integration of artificial intelligence and modeling plugins further facilitates the creation of optimized cutout shapes. *(page 126, top)*

Hypothesis 2: Woodland Dataset

In the research paper titled “Timber structures made of naturally curved oak wood: prototypes and processes” ,[236] authored by Larsen et al., diverse digital methods for quality control and species identification in the wood industry are outlined. Photogrammetry is one such method, involving the creation of a 2D or 3D model from image capture, typically utilizing cameras and drones. Additionally, techniques like LIDAR (Light Detection and Ranging) can yield similar outcomes.[237]

They highlight how sawmills in Finland have successfully employed photogrammetry to record essential information, including species, size, and position of each tree within a forest. The data collected was stored in a dataset, enabling efficient wood availability management. Harvesting machines then capture the dimensions of individual trees and transmit this information to sawmill computers.[238]
This method, executed at the outset of the inquiry, offers enhanced productivity on a larger scale. Furthermore, there is potential to utilize the tool to create a model of the project directly from the 3D geometries of trees.

236. Larsen, 2022, p.494
237. Svilans et al. 2019, p.123
238. Larsen, 2022, p.496

B. Integrate

Upon conducting an analysis and assessment of the potential transformation of a log or branch into a specific timber element, the subsequent step involves integrating it into a timber frame construction. This integration can either occur in parallel with the evaluation process or as a sequential continuation.

Hypothesis 1: From Branches to Frame Parts

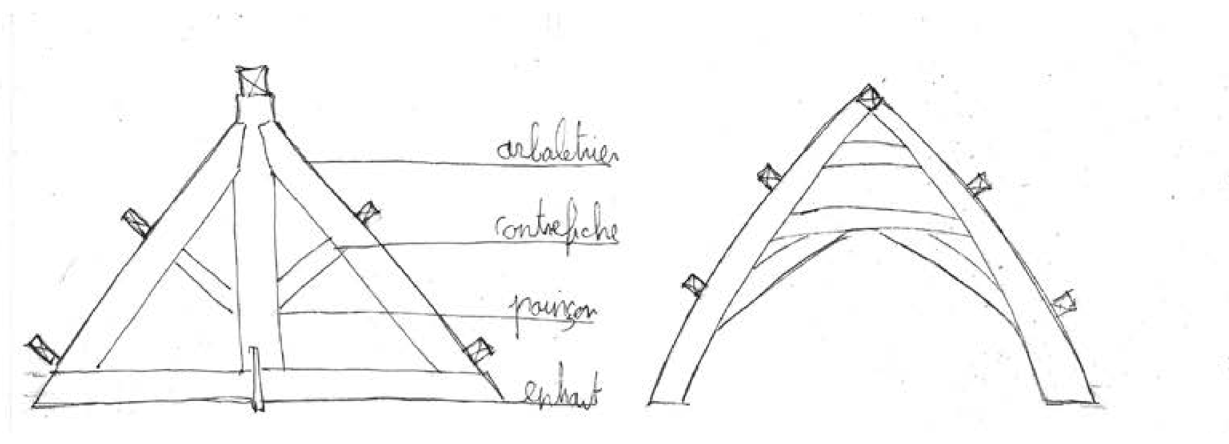
After utilizing orthophoto analysis, a carpenter has the option to straightforwardly align various shapes in a 2D space, thereby creating timber frames. This method, especially when applied to curved logs, echoes the architectural style seen in 15th-century German Fachbau housing types.[239]

The logs can be kept in their original orientation, following the growing direction better. While maintaining the logs in their original orientation aligns with the natural growth direction, limitations arise from the exclusive reliance on 2D curves and the construction of 2D frames.

Furthermore, adopting a perspective of transitioning from branches to construction elements, reminiscent of traditional boat-making practices, involves using certain types of tree forms for certain boat parts.[240]

Leveraging the 3D model of the tree or the orthophoto in this context enables the creation of a comprehensive database of construction elements inherent in traditional wood framing construction. These elements can be aligned with the existing construction typology, encompassing components like *Arbalétrier, Entrait, Poinçon, Contrefiche.*

Notably, the cruck frame type in England utilizes Contrefiche made from curved wood to achieve larger spans, a structural system akin to that seen in the St Cross Hospital in Winchester. [241, 242]



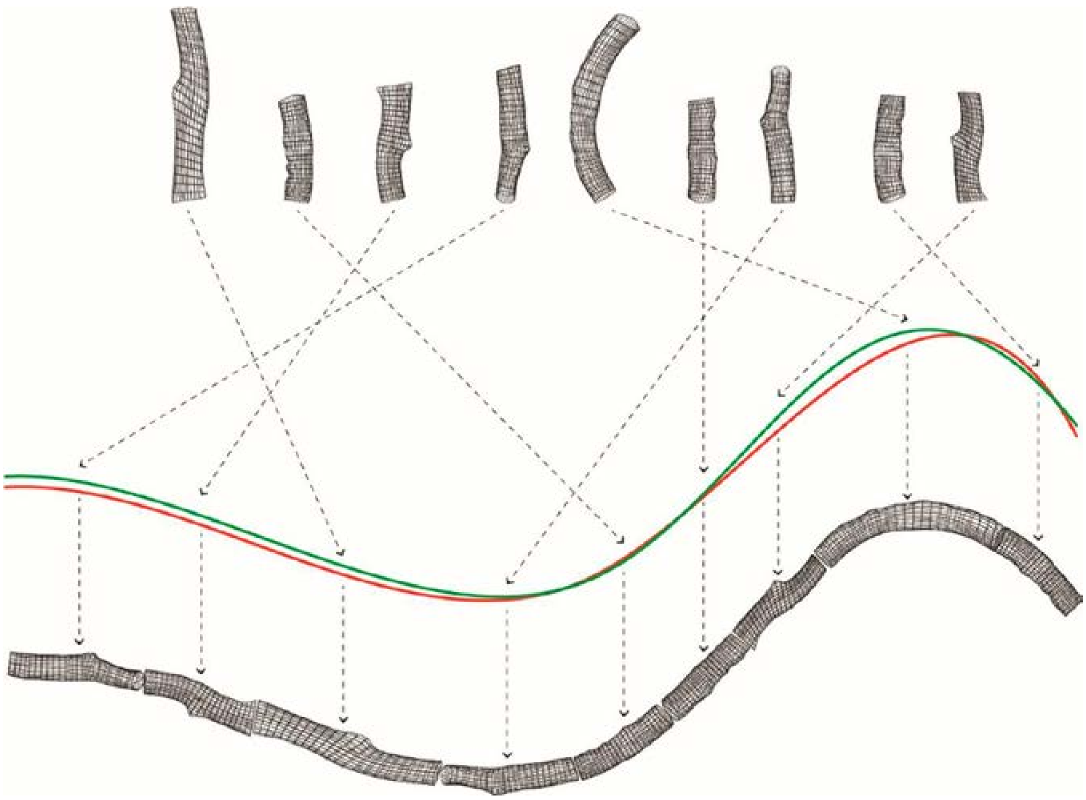
239. Schindler, 2009, p.103
240. Miller, 2000, p.19
241. Larsen, 2022, p.495
242. Schindler, 2009, p.105

Hypothesis 2: Discretization

In their study, Larsen et al. introduced a method to make Zollinger structure through the assembly of diverse curved beams. The process involved scanning each log, transforming it into a 3D geometry, and subsequently incorporating it into a database containing all trunks. Through the utilization of grasshopper plugins and a custom algorithm, they determined the optimal placement of each wood piece within a grid-based system, adhering to the same hierarchical order as the original tree.[2437]

This innovative approach led to the integration of the trunk's natural curvature directly into the design. Instead of resorting to the conventional methods of bending wood or creating glued laminated shapes, the irregularities of the curved logs were strategically employed to their advantage. The subdivision of the curved logs into simple curves proved instrumental in avoiding the complexities associated with double-curved beams.
Furthermore, the potential synergy with the previously discussed woodland dataset could pave the way for an efficient production process of discrete structural elements. By envisaging a fully automated system that selects trees directly from the forest, this approach, when coupled with AI calculations such as Genetic Algorithms, has the capacity to generate diverse iterations of the model.[244] However, a critical challenge lies in the necessity to meticulously scan each tree for precise modeling, emphasizing the importance of comprehensive data acquisition.

243. Larsen, 2022, p.493-495
244. Bianconi et al. 2019
245. Image taken from Larsen, 2022, p.500
246. Image taken from Larsen, 2022, p.499



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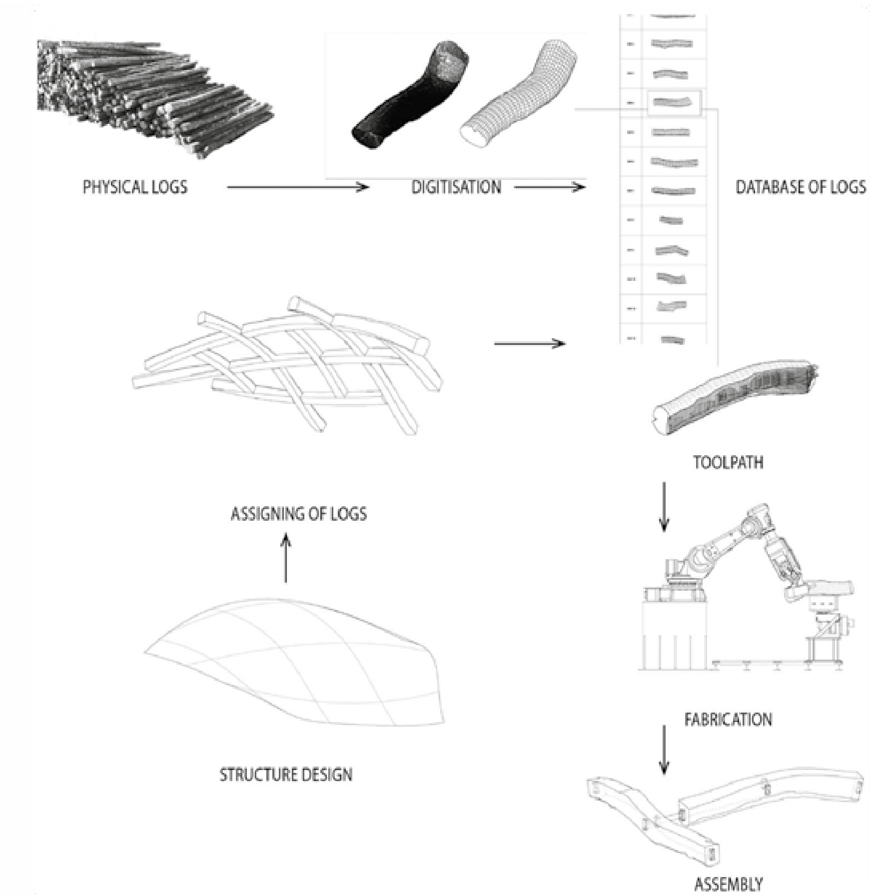

PHYSICAL LOGS
DIGITISATION
DATABASE OF LOGS
TOOLPATH
ASSIGNING OF LOGS
STRUCTURE DESIGN
FABRICATION
ASSEMBLY

C. Felling

Traditionally, carpenters have relied on gathering already felled wood from the forest or requesting the woodland manager to fell a designated tree. However, advancements in technology have introduced innovative solutions to enhance the extraction process and integrate it more seamlessly into specific projects.

Forestry Robots

One such solution involves the utilization of forestry robots. While the incorporation of machines and robots on-site presents challenges due to the irregular and ever-changing terrains, some are equipped with video sensing capabilities to navigate these complexities. On-site construction robots, whether on wheels like the inSitu fabricators or fixed like bricklaying robot arms, already operate in the field. [247], [248]

Establishing a woodland dataset, as previously discussed, could prove instrumental in assisting these robots during on-site operations. Additionally, methods such as personal laser scanning can provide detailed terrain maps to further enhance the robots' capabilities.[249]
Forestry robots exist in the experimental field. Future research program in New Zealand through the Forest Growers Levy Trust and the Ministry for Primary Industries developped new types of felling machines. Richard Parker built for instance a radio controlled tree to tree moving machine.[250] This robotic apparatus navigates by gripping tree trunks and launching itself to another location, enabling access to areas that would be challenging for a human worker to reach. Importantly, these harvesting machines possess the capability to automatically adjust to irregularities in the log, enhancing precision.[251] While the application of forestry robots is currently more prevalent for straight trees, their potential extends to making woodland work safer and harvesting more precise.

247. Paraschо, 2022, p.190
248. Parametrichouse, 2023
249. Holzinger et al. 2022, p.9
250. Holzinger et al. 2022, p.9
251. Larsen, 2022, p.496

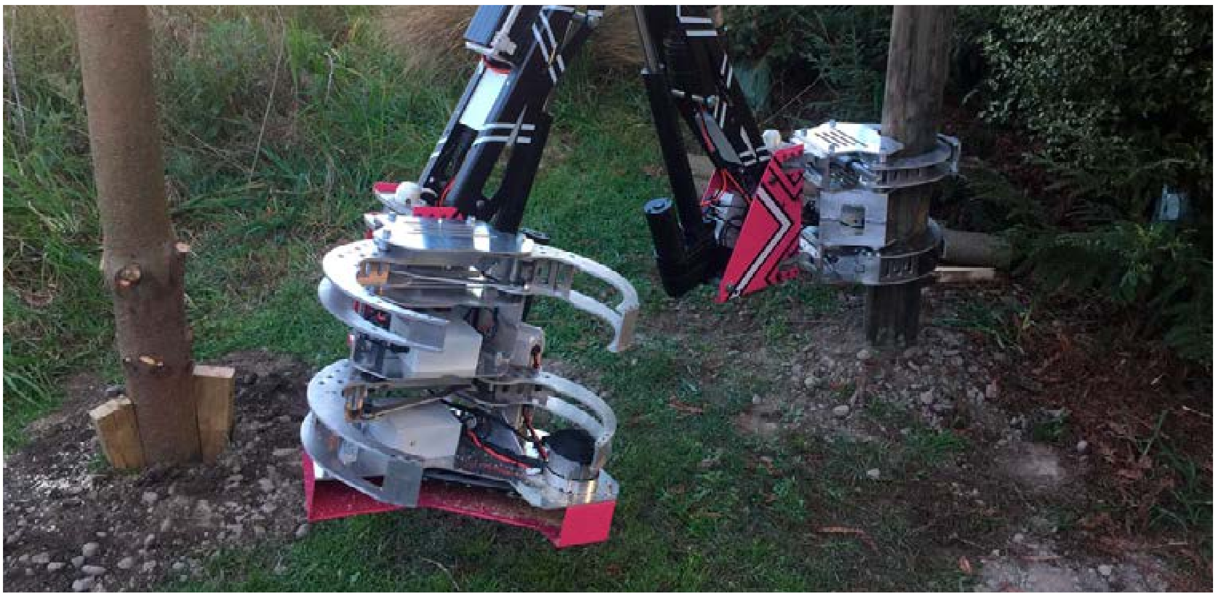
The effectiveness of each method presented is contingent upon the scale and nature of the intended construction project. Considerations for large-scale projects involving ample woodland resources indicate that creating a comprehensive dataset of all the trees could be a valuable investment. Although this process is costly and time-consuming, its completion streamlines subsequent steps in the production chain, facilitating the extraction of wood on a seasonal basis.

Conversely, for smaller scale projects that involve disparate trees, an orthophoto method appears as a more suitable approach. This method is adaptable to the unique characteristics of individual trees, providing a pragmatic solution for more limited resources.

In terms of the building's structural complexity, a distinction arises between those with a two-dimensional (2D) structure and those with a three-dimensional (3D) structure. For projects with a 2D structure, a straightforward photographic solution is deemed more logical. In contrast, projects with a 3D structure benefit from the precision offered by a detailed scan of the trees.

In conclusion, the decision-making process should consider the project's size, the availability of woodland resources, and the structural dimensionality. While each method has its merits, a comprehensive woodland dataset stands out as a conclusive solution for its potential to make a substantial impact on the industry

252. Image taken from,Holzinger et al. 2022, p.10



II. Squaring : from log to timber

Following the selection and felling of a wood piece, the next step involves squaring it. Once each piece is finished, it is promptly placed in the «Épure.» The proposed steps for the squaring process are outlined below:

A. Scan
B. Combine : Nicking, Smashing and Finishing

The nicking phase of wood squaring is typically the slowest and most labor-intensive for carpenters. This stage demands precision and repetitiveness, making it well-suited for a machine to handle efficiently. Additionally, hand tracing can be challenging, depending on the complexity of the log.

Conversely, the stages of smashing and finishing require adaptability. Each time the ax makes contact with the wood, it needs to adjust to curves and defects. These latter steps are usually more fluid in the process, allowing for greater flexibility.

To address these considerations, exploration into the enhancement of these processes with machines will be undertaken. This evaluation of new limits and potentials is typically carried out after the extraction phase, once the wood required for the entire year has been felled.

La Poulaine

In an era predating the existence of sawmills, the construction of ships, houses, and monuments relied solely on human craftsmanship. This manual approach persisted until the 15th century when axes were characterized by small wedges and double-bevels. This tool design facilitated the cleaving of variously shaped logs, particularly in boat making.
Vikings notably employed this technique for squaring and finishing, leveraging its ability to cut fibers tightly. The result was structures, including ships and buildings, with enhanced resistance to water and infections. Consequently, houses and monuments constructed using this method endured for centuries.

253. Image taken from Larsen, 2022, p.495

A. Scan

The intended squared subtraction must be delineated on the bark. It is worth noting that irregularities in the shape do not significantly impact its structural behavior, provided that all the sapwood is effectively removed.

Hypothesis 1: Scanning

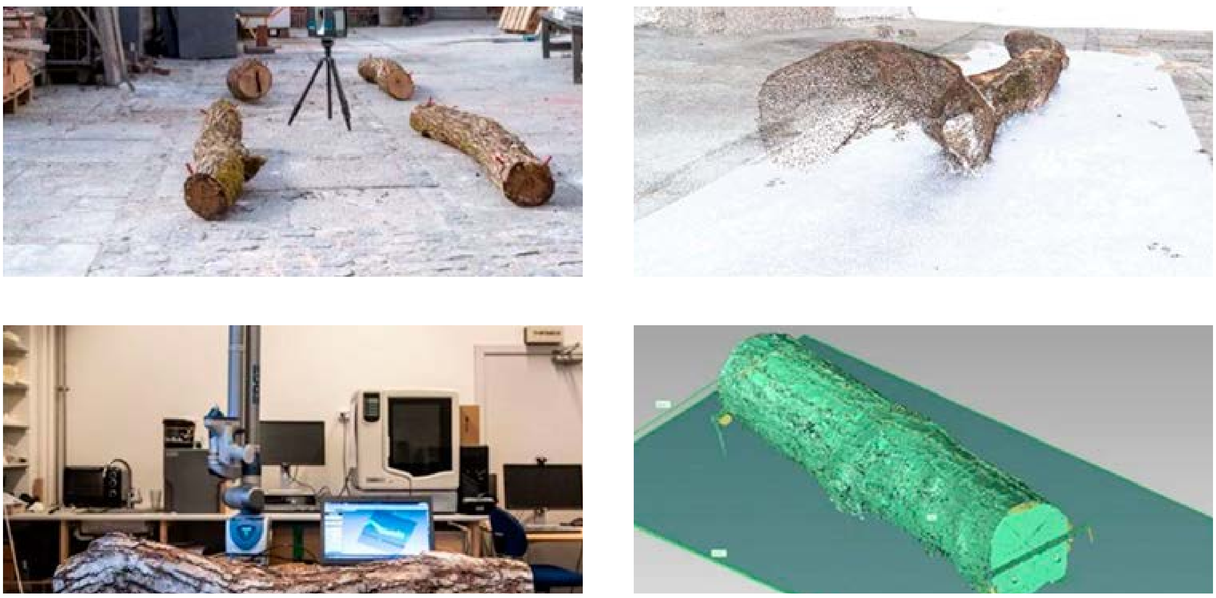
The project by Larsen et al., as discussed earlier, suggests a method involving 3D scanning of the log, modeling all operations, and subsequently using a CNC machine for implementation. Although the scanning process initially slowed down the operation, it paved the way for an automated and precise assembly line.

In this particular case, a handheld scanner was employed to digitize each log, requiring debarking for enhanced accuracy. To streamline the process, a scanning chain could be introduced, utilizing techniques such as multi-sided X-rays or advanced tools like the Faro Focus scanner for consecutive log scanning.
They used then an algorithms and modeling plugins, to obtain an optimized squared shape, derived from the 3D scan, enabling the robot to cut out the shapes according to the given model seamlessly.[254, 255] *(picture bellow)*

Hypothesis 2: Orthophoto

To eliminate the need for time-consuming scanning procedures, the operation could be done using an orthophoto of the log. One can approximate the squaring lines on the picture.

254. Larsen, 2022, p.496
255. Larsen, 2022, p.498
256. Image taken from Larsen, 2022, p.497



Hyp 3: Tracing by Hand

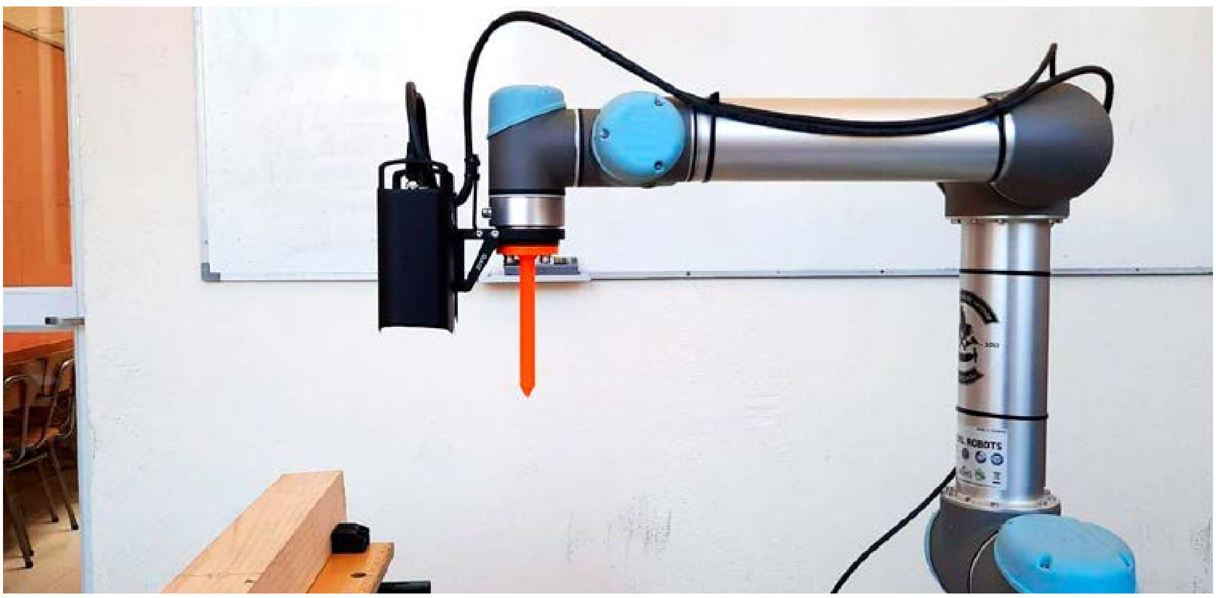
Instead of scanning or using an orthophoto, a carpenter could trace by hand on the log.
The Atelier de la Grande Oye demonstrated that a skilled carpenter can achieve well-squared subtractions without without relying on digital devices

Aguilera-Carrasco et al. introduced in 2023 a hand-drawn language for human-robot collaboration in woodcraft, employing a camera on a robot's arm to translate signs using a database and object categorization. This approach could be applied to wood squaring, allowing the robot to interpret nicking or cutting lines without the need for extensive scanning. [257] *(picture bellow)*

While the squared shape may be somewhat less precise than scanned and computer-generated ones, the difference is largely aesthetic, and the log remains healthy and structurally sound as long as all the sapwood is removed. Additionally, a 3D scan can't differentiate each wood layers unless its used with an X-ray. Finishing with an axe, on the other hand, can adaptively remove any excess sapwood.

An obstacle lies in the readability of marks and signs on the wood for the robot. Aguilera-Carrasco et al. faced challenges even with clean, sawmilled wood, and recognizing marks on unmarked wood could be even more demanding, especially under difficult light conditions.[258]

257. Aguilera-Carrasco et al., 2023
258. Aguilera-Carrasco et al., 2023, p.100983
259. Image taken from Aguilera-Carrasco. et al., 2023, p.100975



B. Combine : Nicking, Smashing and Finishing:

The steps of wood squaring can be combined in different ways

Hypothesis 1: Fully Squaring with a Robot or CNC, 1-2 Robots

The research of Larsen et al., introduced earlers, shows how utilizing CNC technology for the full process enables efficient and precise carving.
After scanning the trunks, the used a CNC milling end attached on a 6-axis robot arm to turn the logs into squared shapes. This approach accommodated logs of varying shapes and sizes.

However, the speed advantage of CNC cutting is not universally significant for complex shapes, with processing times ranging from minutes to hours or days, while a traditional ax can consistently square two logs in a single day. Moreover, CNC cutting sacrifices the benefits of cleaving discussed earlier.

Challenges include compensating for the robot's reach limits and lack of vision. Some logs, such as those used in the Notre Dame reconstruction, can be up to 16 meters long, surpassing the typical 6-meter reach of a robot.[260]
Augmenting the reach with a gantry is an option, but it poses difficulties in on-site applications. Robots on wheels, like inSitu fabricators, allow continuous movements but require manual or computer vision for material localization. [261] Larsen et al. used a rotary table to ensure the robot could access all sides.[262]

ETH Zurich's Chair of Architecture and Digital Fabrication explored novel methods using more than one robot to build wood frameworks. One arm held the timber, for instance, while the other cut it in the right size.[263] A similar application could be possible for squaring long logs. *(image page 134)*
To mitigate reach limitations, one could opt to use or cut logs in smaller lengths, aligning with typologies discussed earlier, such as Fachbau and Zollinger structures, which involve subdivisions of trunks.

Precise measurement of the log's position is crucial in most cases, with Larsen et al. utilizing a real-time tracking system, OptiTrack, featuring marked dots on the material. While cameras and visual sensors can aid in positioning, they become less reliable in uncontrolled environments.[264]

… then Finishing with an Ax

In the restoration efforts for Notre Dame, a hybrid approach was employed for processing larger logs. Initially, a saw was utilized to cut at least two sides of the log. To ensure precision and accommodate the artisan's touch, a deliberate offset of 30mm was retained on the squared log.

260. Parascho, 2022, p.189
261. Parascho, 2022, p.190
262. Larsen, 2022, p.503
263. ETH, 2018
264. Paraschо, 2022, p.193


265. Image taken from ETH, 2018

Hypothesis 2: Nicking with 1 Robot and Squaring by Hand

Nicking, characterized by the creation of 20 cm intervals on a log's side to facilitate subsequent processing, stands as a meticulous and repetitive task. The ax has to meticulously follow the traced line without deviation. A demonstration at the "Atelier de la Grande Oye" by Julien Hentzy unveiled the use of a chainsaw, employed to expedite the notching process. This task's inherent time consumption and physical demands, especially on the carpenter's back, motivates exploration of automation.

For instance, Tom Pawlofsky and Tibor Weissmahr in 7Xstool, utilized a chainsaw attached to a robot arm, cutting stools directly from a trunk.[267] Further innovation surfaced in Achilleas Xydis's workshop named Robarch, where a robot arm, equipped with a chainsaw, contributed to wood manufacturing.[268] *(image page 136, top)*

Implementing a chainsaw on a robot arm is an a effective strategy for enhancing efficiency and maintaining consistency in the notching process. While demanding less time and adaptation for the robot arm compared to full squaring, this approach underscores the potential for optimizing specific tasks within the wood manufacturing process.

...then Squaring with an Ax

Once the robot completes its task, nicks are intentionally left every 20 cm on the side of the log, providing intuitive guidance for the subsequent wood squaring process. Following these nicks, the worker can proceed without the need for additional tracing.

Compared to full squaring with a CNC, Hand tools may lack the precision and cleanliness. They boast the advantage of reaching all parts of the log, regardless of irregularities or length. Unlike CNC processes that may require moving tables or conveyor trays, manual cleaving allows for versatile and adaptable processing. Furthermore, hand tools facilitate the removal of all layers of sapwood, ensuring a waterproof surface.

267. Pawlofsky et a., 2013
268. Xydis, 2018

266. Picture taken from Xydis, 2018

Hypothesis 3: Nicking with 2-3 Robots

Traditional wood squaring by hand is inherently limited to processing laying timbers, restricting its application to simple curved logs. To overcome this limitation, the collaboration of two to three robot arms, as previously discussed, could be employed. One robot arm could hold and move the log, while another operates the chainsaw to create nicks.

In a more speculative scenario, one or two robot arms might carry the log, another robot arm makes the necessary nicks, and a worker squares the wood while it's securely held. However, this approach poses the risk of the robot arm being damaged by the axes' backlash. If feasible, this setup could potentially extend the capability to work on even double-curved timber, with the robots holding and turning the log while the worker performs the cleaving.

Hypothesis 4: Nicking with robot aided hand held tools

An intermediary approach between machines and hand tools involves the use of aids like jigs and templates to enhance human capabilities. Leen et al. introduced a product named JigFab, which allows the setting of custom printed rails and fixtures on materials. This restrains movements and augments the precision of hand machine tools such as Miter Saw, Plunger Router, Drill, Circular Saw, and others.[269]

This system could potentially be adapted for wood squaring during the nicking steps. However, applying fixtures to irregular logs might pose complications. The Adroid from Tian et al. serves as an example of a virtual fixture where a robot arm is attached to a hand tool, and movements are guided by computer-controlled fixtures. *(image page 138)* [270] Sensors and predefined motions enable precise hand tool work without the need for physical fixtures. Nonetheless, the size of the worked trunk remains limited by the reach of the robot arm.

Fixture on Axes

In the context of wood squaring, the smashing and finishing steps could benefit from a virtual fixture. While the worker holds the ax, a robot arm could assist by guiding the ax to ensure it cleaves in the correct directions. However, sustaining a repeated hitting movement might be challenging for a conventional robot arm.

The German Aerospace Center conducted experiments with an anthropomorphic design known as the DLR Hand Arm System. This robotic arm was employed to strike a nail with a hammer, although its design differs significantly from conventional industrial robots.[271]

269. Leen et al., 2019
270. Tian et al., 2021
271. Guizzo et al., 2011

The integration of machines and robots into various stages of wood squaring introduces both new possibilities and challenges. While scanning each log may be a time-consuming process, it provides additional opportunities for subsequent steps. Consequently, a precise and optimized squared timber can be modeled.

Fully squaring the log with a robot can result in a seamless process without interruptions. However, this approach requires visual feedback and the ability to reach all parts of the log, posing challenges in on-site applications.

Experimenting with multiple robots may offer the advantage of working on longer and curved logs without the need for wheels or intermediary platforms.

Lastly, using the robot specifically for the nicking step allows leveraging its accuracy and the adaptability of the worker.

272. Image taken from Tian et al., 2021, p.1

III. “Épure”

Following the initial selection, the “Épure” of the desired frame is delineated on site. The squaring process runs concurrently, and as each log is completed, it is strategically positioned on the drawing. Subsequently, the log is marked and jointed.
The “Épure” serves as a pivotal step in coordinating timber pieces, proving particularly beneficial when handling curved and irregular components and addressing hand squaring tolerances. Positioned between fabrication and construction sites, the «Épure» plays a crucial role in achieving a harmonious integration of the various process steps.

Here is a proposed procedure that makes the steps of the process more integrated :

A. Trace and Place
B. Combine : Marking, Carving cuts and Joints
C. Assembling

Occasionally, expansive areas are required to accommodate the entire framework laid out within the “Épure”. For instance, in the construction of Notre Dame, frames measuring 16 by 13 meters were assembled in the *“*Atelier de la Grande Oye*”*. Recognizing the constraints of limited on-site working surfaces, exploration into enhancements becomes imperative.

Automating joint making and tracing processes holds promise due to their precision and repetitive nature. Conversely, the assembly and «mise sur ligne» demand a level of adaptability more aligned with human capabilities. As part of the exploration, strategies to strike a balance between automation and human-centric adaptation will be investigated to optimize this abilities and the construction process.

Abbundplätzen

During the 13th century, the advent of pre-fabrication marked a significant development, with frames being assembled in designated spaces known as Carpentry Yards. These yards, strategically located in city squares or on the outskirts, served to encapsule all stages of the construction process, ranging from wood squaring to assembling.[273]

273. Schindler, 2009, p.111

A. Aligning

The initial phase involves delineating the axes of the framework and arranging timber pieces atop one another. After each log is squared, it is transported to the "Épure" to maintain a seamless workflow.

Hypothesis1: Tracing with Robot and Hand place on Floor

Arguably the most efficient and precise method for creating a one-to-one drawing involves the use of a robot's hand. Drawing with machines is already common in cutting tables and CNCs, as demonstrated by the CRCL (Laboratory for Creative Computation) at EPFL, led by Stefana Parascho, which employed robot arms to draw with lavish paintbrushes. To overcome the limitations of a robot's reach, very long pens or markers could be utilized for large drawings. Laser pointers or projected images from the top are alternative possibilities. Workers can then easily and accurately position the timber on the floor based on the one-to-one drawing. In cases where the site lacks a large, flat floor, the use of large boards or punctual bench supports under joint areas could be considered.

Hypothesis 1: Drawing on Computer and place by Robot on Floor

Employing a robot to position timber facilitates the handling of large and heavy logs. However, the method of creating the drawing is more nuanced. Timber disposition could be relayed to the robot by the computer, assuming the floor is flat or integrated into the robot's environment. Alternatively, human marks could guide the robot in placing timber, akin to the approach taken by Aguilera-Carrasco et al. Image sensors would need to be affixed to the robot. In both cases, the geometries of the timber elements must be modeled, including their middle axes, and scanning or orthophoto techniques can be applied.[274]

274. Aguilera-Carrasco et al., 2023
275. Mitterberger et al. 2022

Hypothesis 2: Drawing on Computer and hold by 1-2 Robot in the Air

Drawing and laying out the framework on the floor requires a flat surface and results in 2D frames. However, holding the timber in the air during processing can circumvent irregular ground and facilitate the use of 3D frames. Mitterberger et al. propose a human-robot cooperative workflow for assembling wooden structures using rope joints. In this approach, two robots hold wood sticks in the air, while a researcher attaches them together with ropes. [275] The robots bring additional sticks when the first ones are attached, and this process continues until the entire structure is assembled. The shape and order of placement are designed to align with the assembling method, resembling the self-supporting bridge designed by Leonardo da Vinci. This historical example involved one person holding a beam while two others placed beams transversally. The first person then moved to place a new beam parallel to the first, repeating the process until the entire bridge was constructed.

276. Image taken from Mitterberger et al. 2022

B. Combine : Marking, Carving cuts and Joint

Once the elements of the frame are aligned, corrections and joints are traced and cut.
Hypothesis1: Scan and the robot makes joints and cuts

Scanning each timber piece enables the robot arm to cut the joints. However, this approach may potentially slow down the process, as discussed earlier.

Hypothesis 2: Draw on Wood by Hand and the Robot makes Joints and Cut

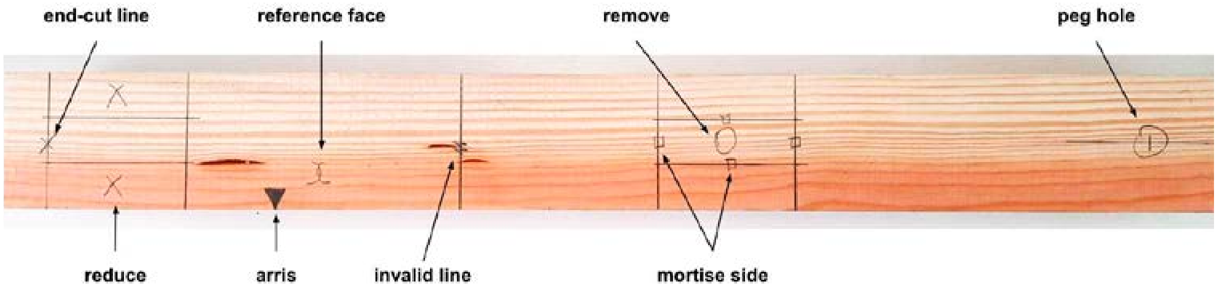
Drawing joints and modifications on irregular and curved wood is a faster manual process. Lines are drawn where timber pieces intersect using rulers and plumb lines. Julien Hentzy noted during the visit to the "Atelier" that cutting joints with chisels is a tedious and time-consuming task requiring precision in intricate geometries. He advocates for the use of machines to expedite this step. Robots can interpret drawn signs made by workers to execute cuts and joints, similar to the approach taken by Aguilera-Carrasco et al. The researchers reinterpreted traditional carpenter signs, used for communication in woodworking, such as cut, reduce, invalid line, mortise side, peg holes, and arris.[277]

The debarked log simplifies the detection of marks, but constraints such as lighting conditions and reach limits persist. To address the latter issue, the marked spot can be moved closer to the machine in each operation. Examples, such as the prototype by Achilleas Xydis using Japanese joinery, showcase the use of a robot hand and chainsaw to carve three different joints.[278]
In cases where skilled artisans are scarce, Japanese industrials like Shimizu utilize CNC machines for producing Japanese joinery with high precision.[279]
The "Atelier de la Grande Oye" emphasizes that finishing the joint with a hand tool can absorb framework deformations, allowing for curved shapes that accommodate wood movement while providing stability.

Jig fabs and Adroid

As explored in the Squaring chapter, a collaborative approach between humans and robots exists. Any hand machine tool can be attached to a robot arm or a custom-made template. For instance, a mortise machine attached to a robot can be guided by human hands, ensuring precise joints while retaining the adaptability of the human touch.

277. Aguilera-Carrasco et al., 2023, p.100978
278. Xydis, 2017
279. Sakurai, Nikkei Asia, 2021



280. Image taken from Aguilera-Carrasco. et al., 2023, p.100975
281. Picture taken from Xydis, 2017

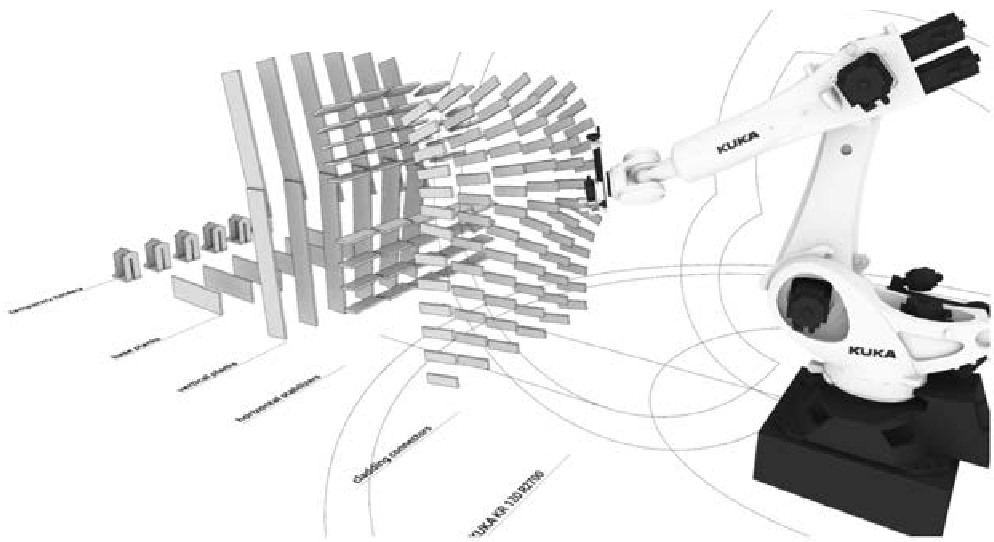
C. Assembling

The framework could be completely assembled by a robot or by hand.
On one hand, assembly by a robot would be quick and precise, but it might face challenges in fitting wood joints together, especially since green wood timber constantly deforms, sometimes requiring force to fit joints.
On the other hand, manual assembly would be slower with limited strength, but the timber pieces could be more easily fitted together. Some laboratories conduct research on human-robot collaboration.

Hypothesis 1: Assemble by Hand and Robot

As discussed earlier, ETH developed a new method where two robots collaborate to cut and assemble wood frames. A researcher then bolts the pieces together with a hand drill once they are mounted.[282]
Tongji University and ArchiUnion in Shanghai proposed a workshop process to assemble curved wood walls with robots holding the pieces and a researcher nailing them together.[283] Numerous similar examples leverage the precision of robots and the adaptability of humans. Robots could hold the elements, aligning them to the desired framework's drawing, while human workers push the timber together and construct the structure progressively. Structures in 2D or 3D could be made without the need for scaffolding or a floor.

282. ETH, 2018
283. Krieg, 2015
284. Image taken from Krieg, 2015



Humans are better suited for marking and fitting, while robots are more adapted for aligning and cutting joints. Since the "Épure" demands both assembling and joining simultaneously, machines and humans need to collaborate.

Manufacturing frameworks while assembling allows for reliable assemblages in construction sites. Placing and aligning can be done by robots for precision and the ability to work off the ground, facilitating the creation of 2D and 3D frames. Marking irregular timber surfaces with joints and cutting symbols may be more adapted with the human hand. Cutting joints is more accurately done by a robot arm, but finishing can be done by hand to absorb deformations. Finally, when the framework is on the floor or mid-air, the human hand is more adapted to fitting together green wood joints.

285. Image taken from Krieg, 2015

Conclusion

The Modern Green Wood Squaring shows what are the limits and the potentials of humans, robots and their collaboration.

I. Selection : from tree to log

The selection process could be enhanced through extensive image surveying of woodlands, creating a comprehensive dataset. This approach provides a more thorough understanding of the various wood species and forms present in the forest. Although it might be a time-consuming and expensive endeavor, once completed, it enables more precise log selection and better anticipation of future projects. Conducting a comprehensive selection of all the logs required for a year's worth of work during the seasonal periods could be a practical application.

II. Squaring : from log to timber

In the squaring phase, each log can be approached through methods like scanning with cameras, manual tracing, or orthophoto. The choice between these methods depends on the complexity of the envisioned framework. From that step, three scenarios are possible:

- The machine completes the full squaring by itself, but it would be slow and demand a full modelization of the log.
- The hand squares all by itself, but it would be too slow and rely solely on the human eye.
- The machine can initiate the process by nicking the sides of the log, and the worker can then trim it following the marked guidelines.

The latter solution permits using the machine in an action that doesn't rely too much on adaptation and avoids humans doing repetitive consistent steps.

III. “Épure”: from timber to framework

In the final "Épure" phase, a collaborative approach involving both robot arms and human workers proves effective. Robots excel at precisely aligning frames, whether held in the air or on the ground. Human hands, with their adaptability, are better suited for marking irregular wood logs and visually assessing the alignment of timbers. Subsequently, the robot's precision is harnessed for joint carving, combining the strengths of both entities in a harmonious workflow.

		hand	machine, information
Selection	Analysis		scan
	Integration		
	Felling		tree robot
Squaring	Scan	chalk on bark	or scan
	Nicking		chainsaw
	Smashing	ax	
	Finishing	ax	
“Épure”	Trace and Place		robot arm
	Marking Joining	chalk	
	Assembling	hand	robot arm

Selection Squaring “Épure”
Trace→Fell→Trace→Nick→Smash→Finish→Trace→Place→Joint→Assemble
Trace→Nick→Smash→Finish
Trace→Nick→Smash→Finish

Fully Automated
Scan→Fell→Scan →Model→CNC→Assemble
Scan →Model→CNC
Scan →Model→CNC

Proposed Process
II.Selection II. Squaring
Analyse→Fell→Scan→Nick→Smash→Finish
III. |
“Épure”Trace
|
Place
|
Joint
|
Assemble

Conclusion

In summary, the first three chapters aimed to reintegrate architects and artisans by proposing a new wood processing method. They drew on historical methods while re-contextualizing them in the contemporary era.

The exploration of the Hand chapter revealed how traditional green wood squaring has the potential to reduce waste and distance while restoring workers' skills.

The exploration of the Machine and Hand chapter exposed how the three subjects are becoming a growing problem in the current industry. Due to high productivity and the large demand for wood, more transports are needed, more waste is produced, and the carpenters' skills and autonomy are diminished.

The Information, Machine, and Hand chapter exposed how a Modern Green Wood Squaring could reduce the impact of waste and transport while enhancing skills and autonomy through the combination of hand, machine, and information.


D12
T11
D12

As questioned in the introduction:

How can we reintegrate architects and artisans into the current industrial paradigm, bridging the gap between traditional craft and modern industrial processes?

Nowadays, working as an independent carpenter is challenging. Small wood makers often struggle to keep up with the market's demand and end up having to purchase sawmilled wood from other countries due to the high prices. Despite these challenges, some wood makers have found alternative ways to respond to industrialization. In a phone interview, Serge Turberg stated:

“Usually, the price of industrially produced wood is around 1200 CHF per m3. L’Atelier de la Grande Oye reaches the same price with axes. That’s because compared to the industry, they don’t have costs of transports, machines and material.
They use curved, cheap wood that no one can use. They bring wood from forests that are around 5km. And they use nearly no electricity or energy to manufacture wood.
But in consequence, they lower their salary and live a modest existence.”

The carpenters of the "Atelier de la Grande Oye" understood that in order to work by hand, and enter again in the market, they needed to compensate through economical and ecological means.
Hand skill itself was in fact the lever that permitted them to attain those objectives.

This theoretical statement explored how to leverage skills in the industrial paradigm to reduce waste and distance.

Skills: Ax

"What are we asking for? Quick and right results. Quick is doable. We asked for a 20 by 20 section, it's there. The finish is correct. It's all there.
Leave those carpenters alone. Everyone makes a different mark on the wood. It's the guy's heart. The Cupule is the carpenter's signature."

Those were the words said by Serge Turberg in his Forge. Not only does the hand give uniqueness to timber construction, but it has economical and ecological advantages.
In today's industry, workers' autonomy is already leveraged to make wood conversion more efficient. However, these tasks are limited to simple tasks in sorting and machine handling. Workers should get involved as well in work needing adaptability and problem solving, where machines lack.[286] With hand tools, humans can work anything anywhere. The ax can cleave in curved irregular shapes that are unusable for current sawmills.
The "Atelier de la Grande Oye" has proven however that machines can improve hand work when used in the right moment.
The proposed solution leverages the workers' skills with the use of the ax.

Distance: On Site

The Machine chapter exposed how transport should be limited to reduce CO2 emissions and wood diseases.
New means of transport have permitted moving wood in all places since the 19th centruy. Combined with industrial sawmills, wood making has got drawn since in the open market. Today the industry produces as a consequence a large part of global transportation emissions.
Contemporary projects need to reduce distance in the process. Transforming wood in local areas would lower prices, pollution and the probability of contracting diseases and insects.
The proposed solution is an on site approach to wood conversion. Wood should be processed directly in the extraction areas, or in its nearest neighborhood. Additionally, it should encapsulate all steps in a single space.

Waste: Bottom-Up

Coniferous species are characterized by fast growth and straight, ductil trunks while oak has irregular curved tough logs.[287] In consequence, the construction industry uses mostly straight spruce for building and throws the rest in heat and energy.
Turning wood into energy releases, however, CO2 which would have been stored if it was transformed into a construction element.[288]
Using of curved wood could reduce the wasted material but also promotes more complex and healthy ecosystems. Using species like oak could promote polyculture and reduce the spread of infections like bostriche.
The following process proposes a wood conversion that augments the use of unwanted wood in a bottom-up strategy. The traditional seasonal cycle of wood squaring will be respected.

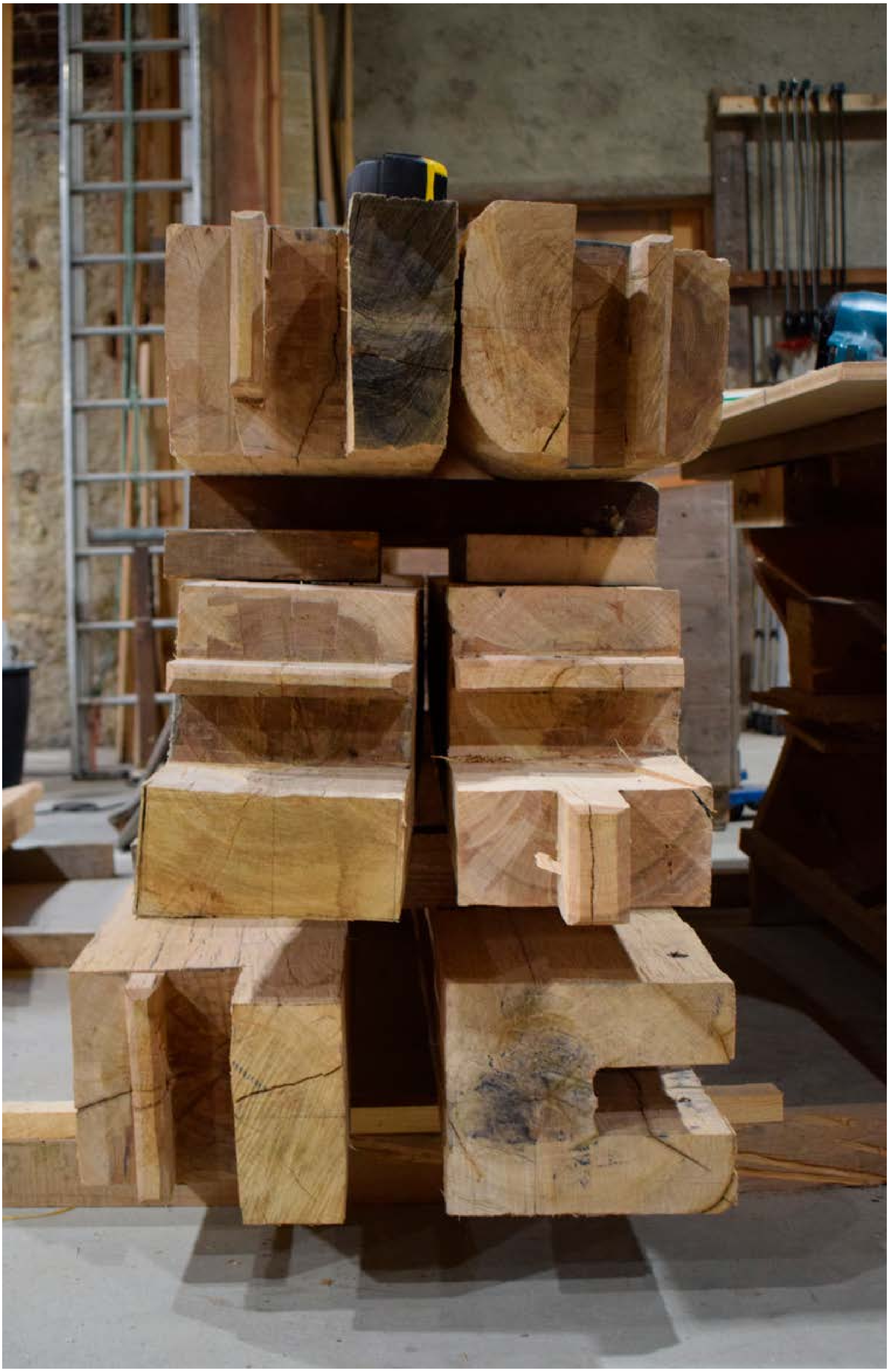
286. Paraschо, 2022, p.195
287. Larsen, 2022, p.495
288. Leturcq , 2018, p.3

Turberg continues :

"In Switzerland, it's over; the prices are too high, and there isn't enough available work to train in the ax way. Compared to France, we have a smaller population to work with and fewer prestigious buildings to renovate. Additionally, in Switzerland, there are many more taxes, and life is more expensive, and health insurance is not covered. La Grande Oye has entered plainly the market and they do more than just renovations, but the context is different.
Renovation might be a lever for the method in Swiztelrand, but green wood has potential not only in construction but also in decoration, furniture, and smaller constructions."

Introducing this approach in Switzerland might be more challenging due to differences in the cost of living and wood prices. Carpenters in Switzerland often purchase wood from France because it is more cost-effective. Interestingly, larger producers like JPF-ducret may be more sustainable than smaller ones because they can afford Swiss wood. In our context, both paradigms provide important lessons.
With growing demands in wood, Scierie Zahnd needs to augment their productivity every year. They fight alone for a more sustainable and widespread use of wood. They have as a result football fields like storages and constant flow of trucks.[289]
The quality of softwood is diminishing and prices of sawmilled wood are augmenting. Thierry Zahnd estimates that in a few decades, Spruce wood might be unusable for the industrial market.
Prices of transports and machines are augmenting due to energy's costs.
Rapport of the OFEV, "Annuaire La forêt et le bois 2022", states that price of Sawmilled wood increased of 25% from 2021 to 2022.
Other producers, like carpenters and architects can take the opportunity to answer the market's growth. They would in fact gain competitiveness, by manufacturing without intermediary enterprises, without energy consuming machines and with local and economical wood.

289. OFEV, 2022, p.84



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JPF-Ducret, 2023
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Scierie-Zahnd, 2023
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Turberg, 2023a
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Turberg, 2023b
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