Parts-In-Progress

by

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ABSTRACT

Construction and demolition materials contribute significantly to the waste stream in the United States with the EPA noting in 2018 that the construction and demolition industries generated 600 million tons of debris. Climate change, continued urbanization with population growth, and increasing demands for new and renovated buildings bestows architects with a daunting responsibility of dealing with the repercussions of material usage. Many architectural projects have been developed to recoup construction waste streams, turning discarded materials into useful building materials. However, there is an alternate strategy to address these issues. Design can instead start from the other end of the material stream, accepting that buildings are built with finite life cycles to plan for the disassembly of architecture.

Parts-In-Progress is a design methodology centered around assembly and disassembly, using standard dimensional lumber connected with custom digitally fabricated parts. The assemblies of this design experiment are at the scale of architectural components and furniture. These prototypes are constructed from the same set of materials with a range of connections and joints. Digitally fabricated parts are used as smart jigs that are tools for fabricating said assemblies and guide bolted connections. The fabrication techniques of *Parts-In-Progress* requires minimal amounts of manipulations to stock materials, in order to preserve them for maximum reassembly possibilities or alternative reuse.

As a parts project, serialization is seen as an advantage. However, the effectiveness of serialization is not found in the reproduction of a singular part, but is instead hijacked from the existing mass-produced parts of the existing building materials logistics network. Lastly, standardization in joints between materials are designed as a range of possible connections around specific dimensional constraints. These variations in connections allow for unpredictable outcomes in their respective assemblies, making it possible to construct the most standard appearing assemblies to the most abnormal assemblies. In the terms of *Parts-In-Progress*, this is the concept of “calculated precarity.”

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Thank you to my committee members Caitlin Mueller and J.Jih. There is no way this project would have been possible without all your valuable input. I aspire to some day be as respected and well-regarded as you are.

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池田先生と岡安先生と前川先生は教えてくださってありがとうございました。日本語の先生のおかげで、今はちょっと日本語を話せます。私の最大のひみつはMITの中で一番好きな先生が私の日本語先生です。本当にありがとうございました。私は日本語の勉強を続けたいですよ。
クリスさんとMIT Japanの家族、ありがとうございました。毎週Japanese Lunch Tableに行っているのが大好きでした。
かりん・ナカムラさんはいい友達になってくれてありがとうございます。いつもかりんは私にエネルギーをくれます。
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Lastly, thank you to SA+P and the larger institution. I never thought I would love MIT as much as I do.

Kimball Kaiser, MIT, May 2022

To Mom, Dad, Dara, and Dirk.

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PART I

Prologue

PART I
Prologue

My first introduction to architecture was not through higher education, but through the construction industry. My family is full of tradespeople and just like my father, my first job as a teenager was in construction. At that point I was involved in wood-light-framing, concrete, drywall, roofing, and demolition. My first experience in the profession of architecture was also at a design-build firm, where in several instances I was constructing details that I had previously drawn in the office.

Whether intended or not, the act of building, making, and fabrication has continued to be part of my work throughout my education and my professional experiences in practice. As a prequel to this thesis project, Jonathan Chavez, Adam Shilling, and I received a small student research grant as undergraduate architecture students to develop our own design-build project. Together we built the B.O.B., a small architecture in which due to our limited budget as well as our interests, was largely constructed from construction waste materials. These materials we mostly collected ourselves from active construction sites. I returned to this project several times as I have worked through this thesis project, now at a different university, but also in an incredibly different context and time.

This project takes a completely different approach to a mode of working, which I hope builds upon these prior experiences and takes advantage of everything that I have learned and been exposed to in the past few years. It should also be noted that I started my MIT experience in the midst of the Covid-19 Pandemic in 2020, with all of my classes being held completely remotely online. My first year access to shop spaces was incredibly limited. I could not be more fortunate that during my second year I have had access to the tools to successfully complete this project. It was a pleasure to be able to share my project with my reviewers, classmates, and friends in person.

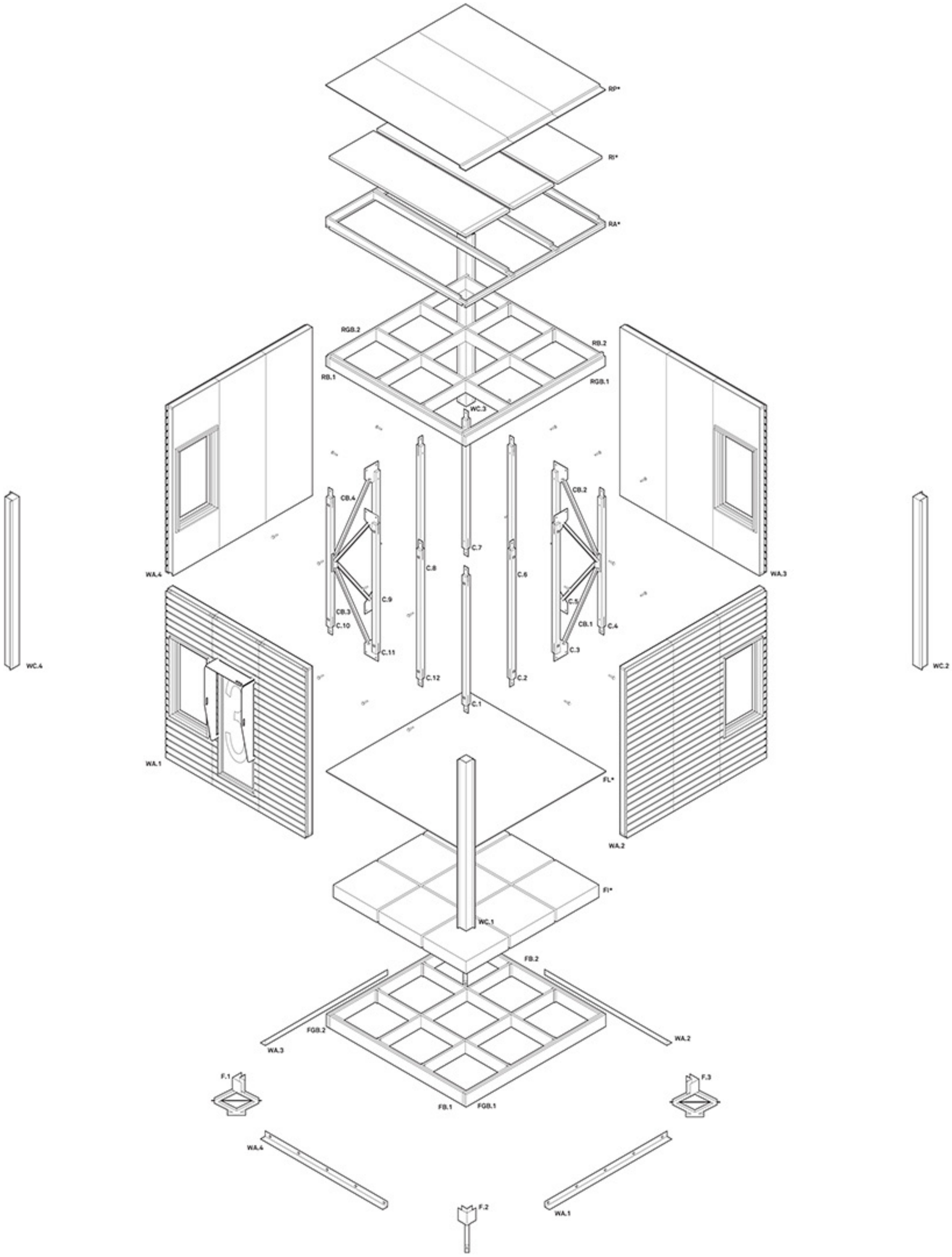


Fig. 001: B.O.B., Jonathan Chavez, Adam Shilling, Kimball Kaiser.

Fig. 002: B.O.B., Jonathan Chavez, Adam Shilling, Kimball Kaiser.

PART II

Recycling vs Dissassembly

PART II
Recycling vs. Disassembly

Construction and demolition materials contribute a significant waste stream in the United States with the EPA noting in 2018 that 600 million tons of construction demolition debris were generated. This amount is double what is generated by municipal solid waste. [1] These figures become ever more concerning in the face of climate change, as the building sector itself is responsible for up to 40% of global carbon emissions. Within the building sector, 28% of emissions are derived from annual building operations, while building materials and construction (typically referred to as "embodied carbon") are responsible for 11% of this value.[2] Global building floor area is also expected to double by 2060 as urban growth continues to intensify.

The increased need in global housing is just one example of how the demand for new buildings will continue to grow. As the UN predicts, the world's population will have increased by another 3.6 billion people by the end of the century.[3] Because of increasingly aging populations, people are staying in their homes for longer, thus affecting existing housing markets. Therefore, the cycle of available housing is delayed each year, increasing the demand for new housing, resulting in an estimated demand for more than two billion new homes by the end of the century.[4] Designers are presented with the challenging situation of figuring out how to address the resource scarcities and climate responsibility of our future, while meeting increasing demands for continued building across the world.

Because of these said pressures, there is a large project for finding and sourcing efficient ways to salvage, recycle, and reuse existing building waste materials. Many forms of demolition waste can already be recycled to produce new materials. Discarded concrete and rubble are often recycled into aggregate for things like asphalt and new concrete products. Metals like steel, copper, and brass are valuable commodities to recycle.[5] However, the fact remains that while demolishing is a wasteful practice, the recycling and reuse of architectural materials is often laborious and inefficient. This is simply due to the fact that buildings are generally not built to be taken apart. Construction materials often resist reuse, as they are often manipulated or cut to fit specific uses, and assemblies are commonly made with bonding and adhesives. Recycling and reuse then comes with extended labor times of processing all these used materials, making virgin materials cheaper than recycled ones. In some cases, attempting to salvage a building can cost more than 80 percent of what it would to demolish it.[6]

However, while there is plenty of room for the continuation of the development of practices that include the use and redesign of waste materials, there also is an opportunity for architects to approach the issue from a different angle - designing for the planned disassembly of architecture from the start rather than simply attempting to recycle existing construction and waste materials. Design for disassembly recognizes that buildings have a limited lifespan. With this in mind, fundamental decisions about materials and joinery are made to be accessible and reversible.[7] The goals of design for disassembly also includes creating projects and buildings that are enduring, yet eliminate waste and strive for a closed loop of a circular economy of materials. This entails a recovery of the systems in a building, components and materials, and a serious analysis of the material supply chain in reverse. The EPA also considers this to be a worthy topic to address in sustainable materials management. Some strategies to use when designing for adaptability, disassembly and reuse include:

- Developing an adaptation or disassembly plan with key information (e.g., as built drawings, materials, key components, structural properties and repair access and contact information).
- Using simple open-span structural systems and standard size, modular building components and assemblies.
- Using durable materials that are worth recovering for reuse and/or recycling.
- Minimizing the use of different types of materials and making connections visible and accessible.
- Using mechanical fasteners such as bolts, screws and nails instead of sealants and adhesives.
- Planning for the movement and safety of workers to allow for safe building adaptation, repair and disassembly.[8]

Parts-In-Progress is a project fully invested in disassembly, arguing that while waste material is a problem to solve, it is only one part of the story. A larger reconsideration of the ways in which we use materials must also start from the beginning, not the end, of the material cycle.

PART III

On Parts

PART III
On Parts

Buildings have been made of standardized parts for as long as the recorded history of architecture. The use of clay bricks, the most original hand-held building module, has recorded use in some cases as early as 6500 BC.[9] In the 20th century, it was modernization and industrialization that improved the standardization of mass-manufactured parts using reproducible, standard dimensions and larger systems of modularization and various component assemblies to produce new architectures.

Konrad Wachsmann, a German modernist architect mainly known for his contribution to the mass production of architectural components, had a career perfectly represented by architecture's history of developing a project around modularity and reproducible parts. Notably, while in exile from his native Germany, Konrad Wachsmann in collaboration with Walter Gropius designed "The Packaged House System." The system was a conceptually rich design for prefabricated housing in the mid 20th century.[10] The prefabricated structures were based around a universalized jointing system that would connect multiple prefabricated wall panels and add rigidity to the larger structural system. The homes were made of proprietary parts that were flexible to different arrangements that suited individual designers, yet the dimensions of the system were in a strange opposition to the logics of standard produced material dimensions. For example wall panels were 3'-4"x10' (in order to add up to a total of 10' feet in divisible increments), but had no relation to the industry standard of 4'x8' plywood panels. Thus windows, doors, and all other architectural fittings would be modular only to this specific system. Alicia Imperiale argues that an open system would actually be a system where metrical dimensions would coordinate with a vast array of industrially produced materials and equipment instead.[11] However, despite the devotion to perfecting all the parts and pieces contained within Wachsmann's universal connector, the Packaged home ultimately failed as it became apparent that the panel connector was too expensive. Eventually the "universal panels" were replaced with standard joists and framing.[12]

Besides the packaged house system, Wachsmann was also involved in designing structures for military operations, mainly aircraft hangars.[13] These space-frame-like structures are based off Wachsmann's "Mobilar" tube joints.[14] These projects represent most of the ideals that still persist among various modular, prefabricated projects still in design today. The tubular members, which are standard pipes connected by nodes of intricate universal connectors, can be assembled without riveting or hand-welding. This design strategy therefore permits shop or field erection. In a manner not dissimilar from that of the "Packaged House," the ingenuity of the design lies solely in these highly articulated joints, in which several pieces slide past each other and interlock to form a sturdy connection. Because the structure is dependent upon a connection with a standard element in an ever expandable fashion, it is therefore intended to be amenable to easy extension or modification. This also means it is a system fully open to complete salvage.[15] While architects often argue for difference or invention,

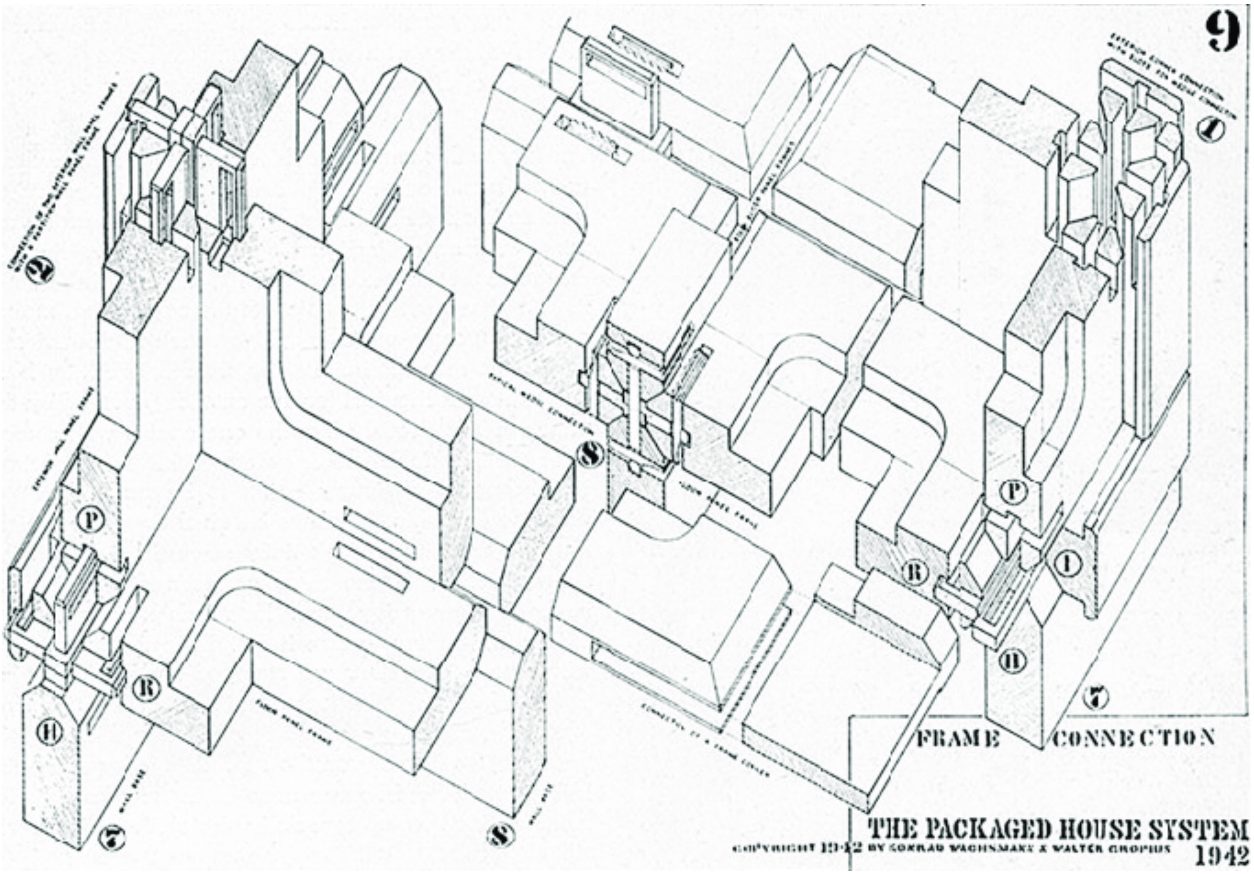


Fig. 003: Konrad Wachsmann, Packaged House Connections. https://www.researchgate.net/figure/Konrad-Wachsmann-and-Walter-Gropius-Frame-connection-of-the-Packaged-House-System_fig16_339948319.

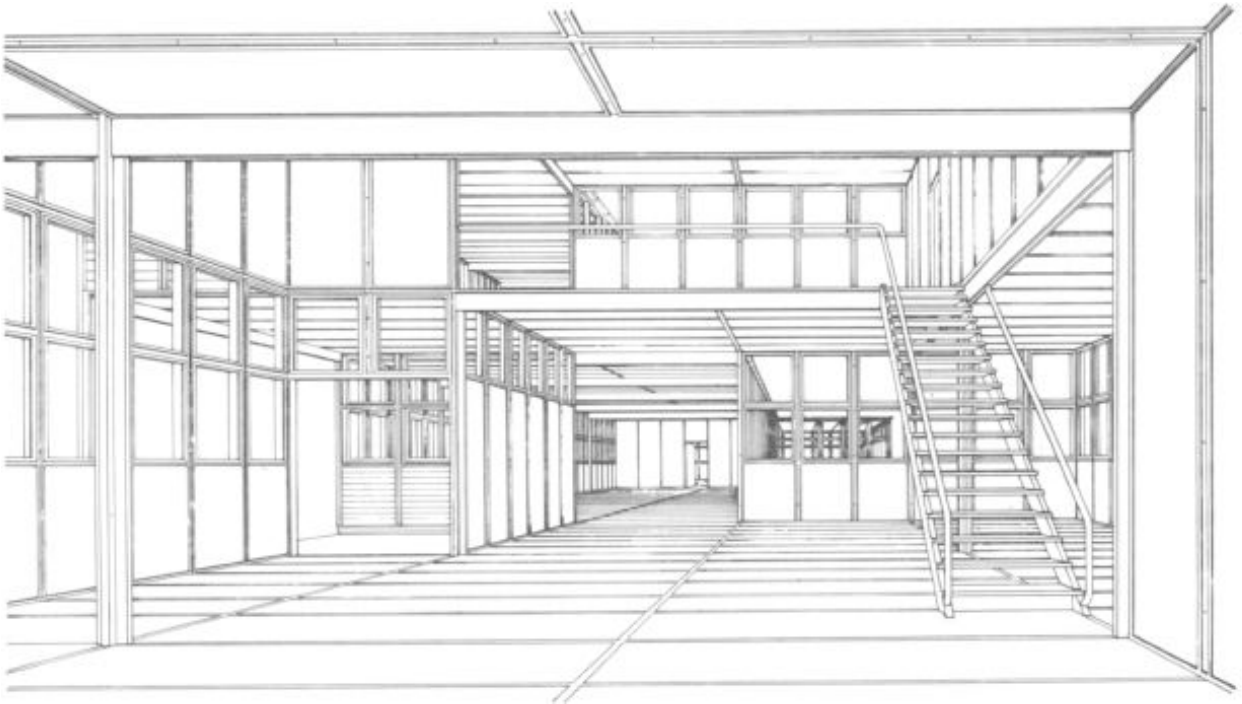


Fig. 004: Konrad Wachsmann, Packaged House System. https://www.atlasofplaces.com/architecture/usaf-aircraft-hangar/.

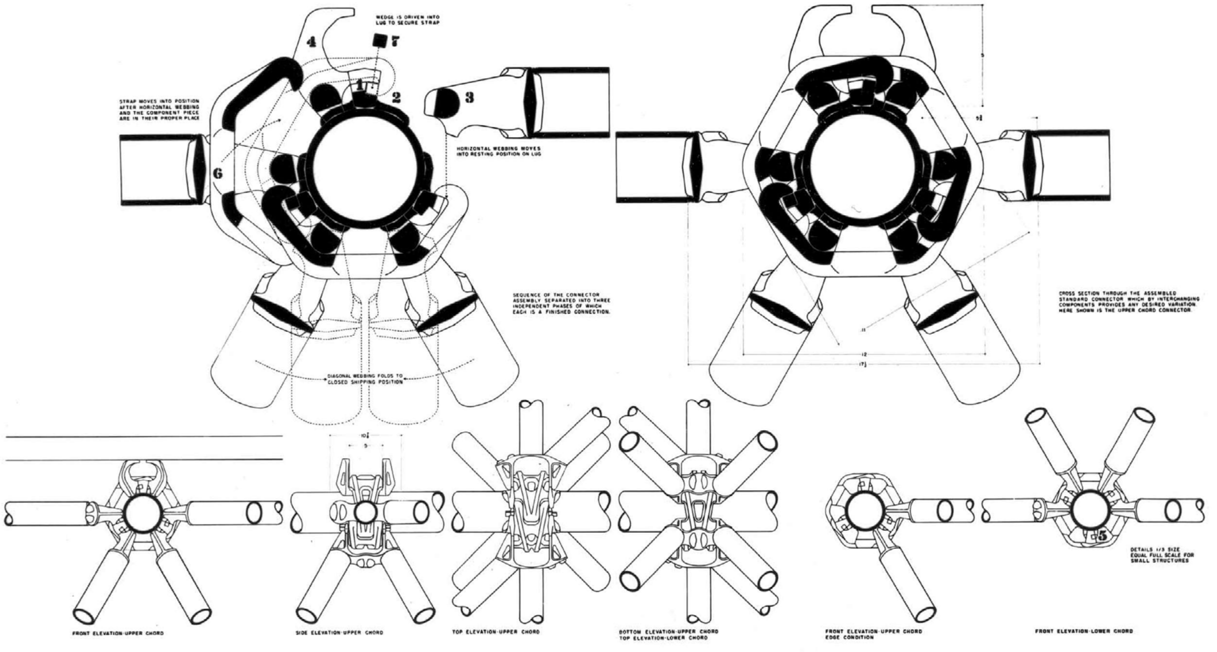


Fig. 005: Konrad Wachsmann, Steel Frame Joint. https://www.atlasofplaces.com/architecture/usaf-aircraft-hangar/.

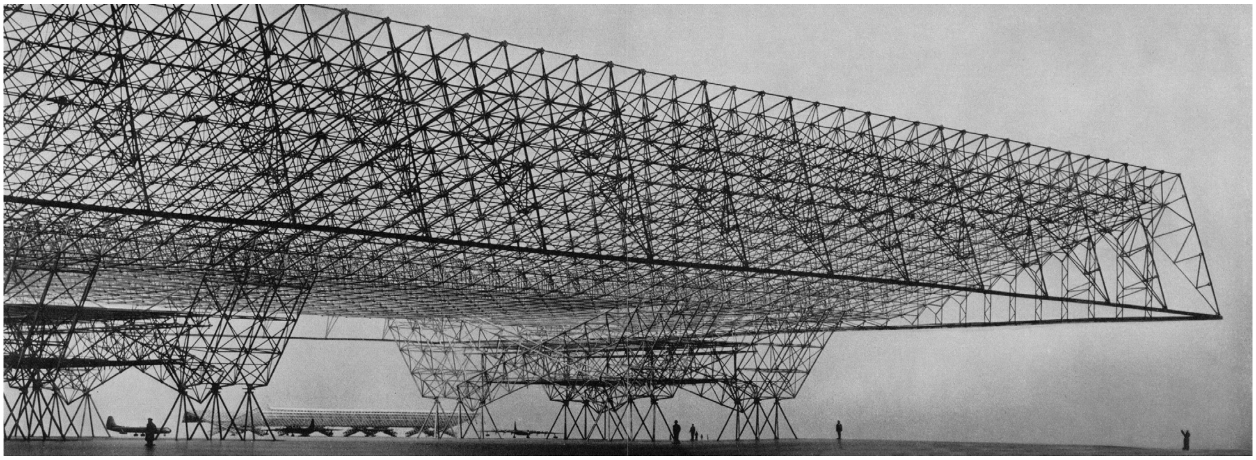


Fig. 006: Konrad Wachsmann, Aircraft Hangar. https://www.atlasofplaces.com/architecture/usaf-aircraft-hangar/.

these ambitions are not so different from contemporary parts projects.

However, in many ways it is once again technology that has changed vastly and therefore shifted architectural strategies around assembly. It is impossible to consider the parts of contemporary architecture projects without the influence of digital fabrication. It is now convention for an architecture student to learn how to operate computer-numerical-controlled (CNC) laser cutters, 3D printers, CNC milling machines, and and other digital fabrication technologies. It has now been a decade since Neil Gershenfield wrote "How to Make Anything," arguing that the coming revolution in digital fabrication would become more personalized and accessible to the individual user, paralleling the historical trajectory of personal computing.[16]

However in the ethos of *Parts-In-Progress*, the production of parts is not meant to be involved in a culture of complex digital forms, highly particular one-offs, or mass customization. What is more of interest here is the fact that digital fabrication provides the ability to turn, "data into things, and things into data."[17] All this information then can be shared, modified, and reproduced digitally by different agents in different locations with different tools.

This aspect of digital fabrication is referred to by many names, but is often most closely associated with the term "open source," a phrase that originates from software development. Open source is often defined as a reconsideration of property, ownership, or individual authorship in light of collective projects that are open to modification, adaptation, and advancement by many actors working cooperatively. Steven Weber's definition of open source in *The Success of Open Source* is as follows:

> Open source is an experiment in building a political economy—that is, a system of sustainable value creation and a set of governance mechanisms. In this case it is a governance system that holds together a community of producers around this counterintuitive notion of property rights as distribution. It is also a political economy that taps into a broad range of human motivations and relies on a creative and evolving set of organizational structures to coordinate behavior.[18]

Architects' fascination with open source concepts in coordination with the developments in digital technologies are also well noted as a potential shift to the ways architects author and publish their own work. In *Digital Property: Open-Source Architecture,* Antoine Picon writes:

> Digital technologies, and digital fabrication in particular, have profoundly changed the status of architectural design. While the design process has been accelerated, the results, generally in digital format, can be indefinitely circulated. In theory, its physical translations, from prefabricated parts to entire buildings, can now be replicated with great fidelity or customised at will to adapt to specific needs. Because design now travels at spectacular speed and can easily be shared and modified, information in digital format has also opened new perspectives for collaboration.[19]

However, while architects working digitally often attempt to achieve an open source ethos, open source culture still arguably thrives better at the scale of machines and devices (in terms of open hardware).

This culture at MIT is rightly available to architecture students through various projects and interactions with other research groups across the university. Many architecture students take the heralded Media Lab courses run by the Center for Bits and Atoms titled “How to Make Anything” and “How to Make Anything that Makes Almost Anything.”[20] Class requirements include the expectation to make one’s own electronics, program one’s own device, and operate a fully functioning machine of some type, in addition to taking ample documentation of the process. This documentation is always produced to be shared with other classmates and future students as an open resource on independent student websites. It is the documentation then that makes these projects truly open. They serve as guides for reproduction or alteration, and more importantly unlock the resources and the knowledge of the class for further development beyond the original student projects.

This culture has been infectious in nature, even creeping directly into the architecture curriculum at MIT. In 2021, Zain Karsan took machine building directly to an IAP workshop and then later to a full option studio. Because of the Covid-19 pandemic, the concept could not have been even more timely, as students were apart from fabrication spaces with school-owned machinery and making was done in isolation at home. Thus, the class was based around every student building their own “TinyZ,” a small format 3-axis CNC machine made with aluminum framing, hardware, a purchasable controller board, a standard power supply, and finally a Dremel tool acting as a router end-effector.[21] Students then made at-home digital fabrication projects ranging from furniture scaled objects to adding an additional rotating axis to the TinyZ for CNC milling around linear objects like found branches and sticks.

It is important to note that because of the larger culture present at the school fostered by the "How To Make" curriculum and the open documentation of the concurrent studio course of the TinyZ, new machines such as the Direct-To-Substrate Printer (DTS) were developed independently outside of the class.[22] It was open documentation and open hardware that enabled two students, with almost no experience building their own tools for digital fabrication, that made the DTS possible. The DTS is an inkjet flatbed printer with motion control in 3 axes, allowing one to directly print upon multiple substrate material types and thicknesses, as well as on unconventional surfaces that may be topologically modified or irregular in nature. These are the true values of an open source concept — that while expertise and significant knowledge is required to produce machines that can be controlled with computer numerical control, if these machines are documented and shared as open hardware, it is possible to see the creation of new iterations, custom adaptations, or new machines. In the case of the DTS, which was built upon open documentation from the TinyZ as well as inkjet printer sources, the work included electronic design, electronics production, embedded programming, and machine

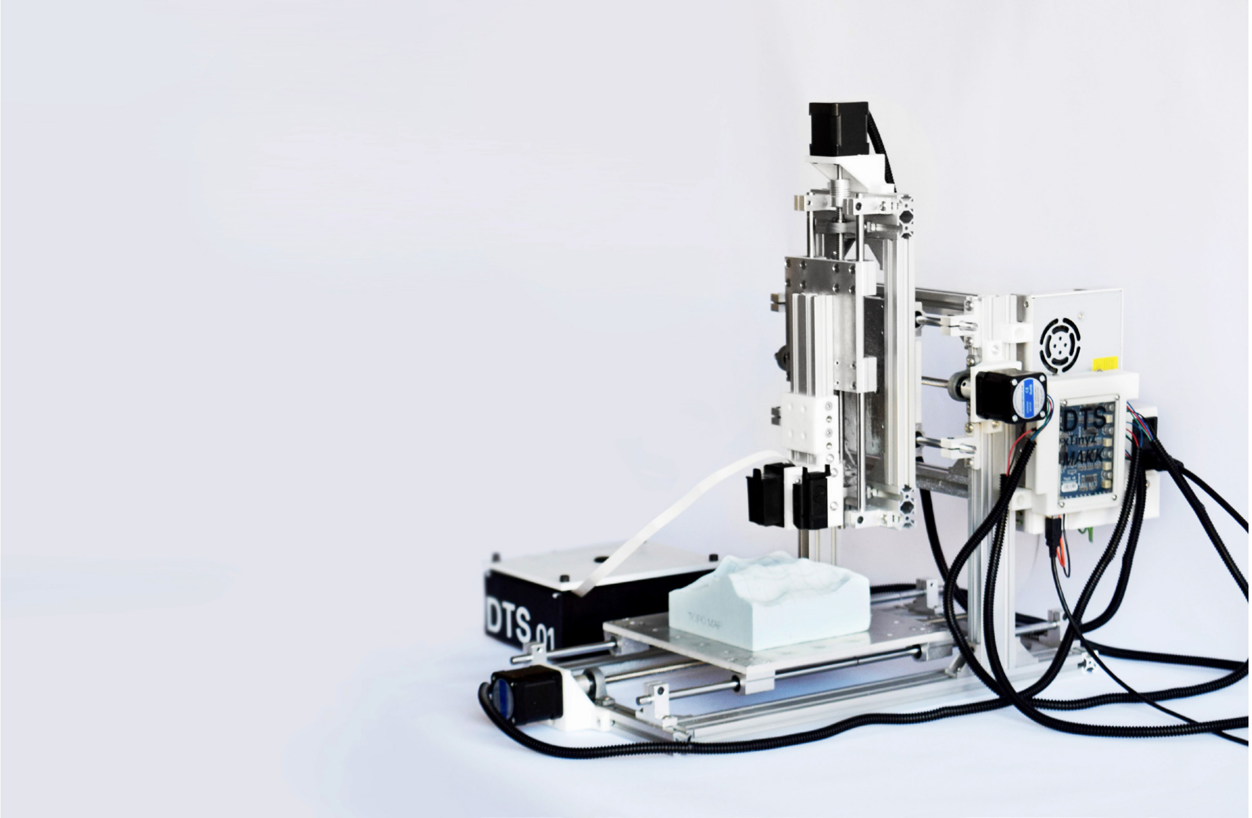


Fig. 007: DTS Printer, Maryam Aljomairi and Kimball Kaiser.

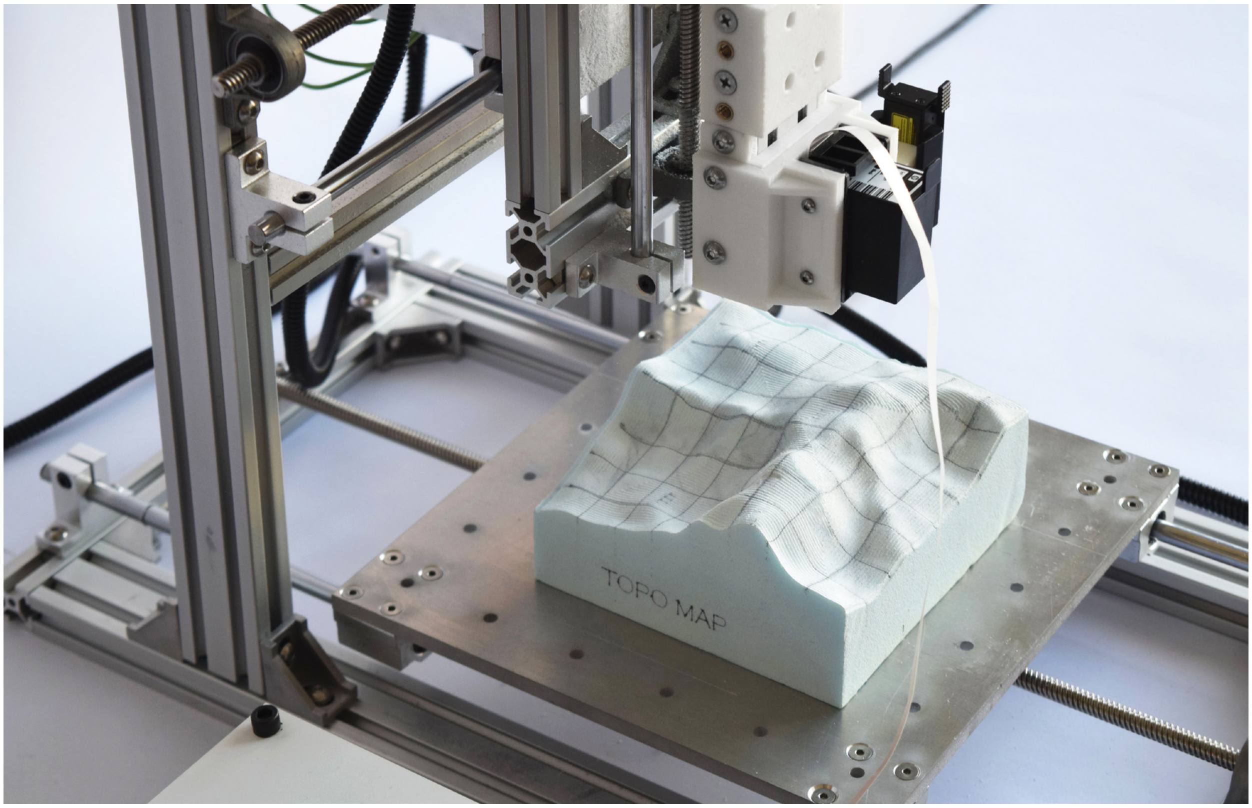


Fig. 008: DTS Printer, Maryam Aljomairi and Kimball Kaiser.

development.

To prove the point even further in the aspects of open source development is the concept of "forking." This metaphor describes the nature of how open source projects can be taken by a developer and diverged enough into a distinct enough project that it becomes an entirely different open source project, similarly to how two branches might grow from the same singular stalk on a tree.[23] In the case of open source hardware, these modifications become even more evident in an open project at the product scale. For example, a mechanical keyboard is a relatively straightforward device for human and computer interaction as an input device that is essentially a series of switches. Through open source documentation, it then becomes very simple to consider making a new keyboard design off the alteration of an existing design.

In the case of "mk01," this meant building on top of an open and existing design for a PCB that was openly shared on the internet for a 63-key keyboard with an OLED display and an encoder knob to create a completely new device.[24] In the spirit of true forking, this meant making a few simple changes in dimensions for a different physical form, adding 5 more keys, and installing a different OLED screen. Not only was the physical hardware modified, the programming was adapted as well to change the use case of the knob, display, and additional keys all built upon a common firmware that is also open source.[25] Not only was the software and hardware forked into a new sharable project, the physical design was also

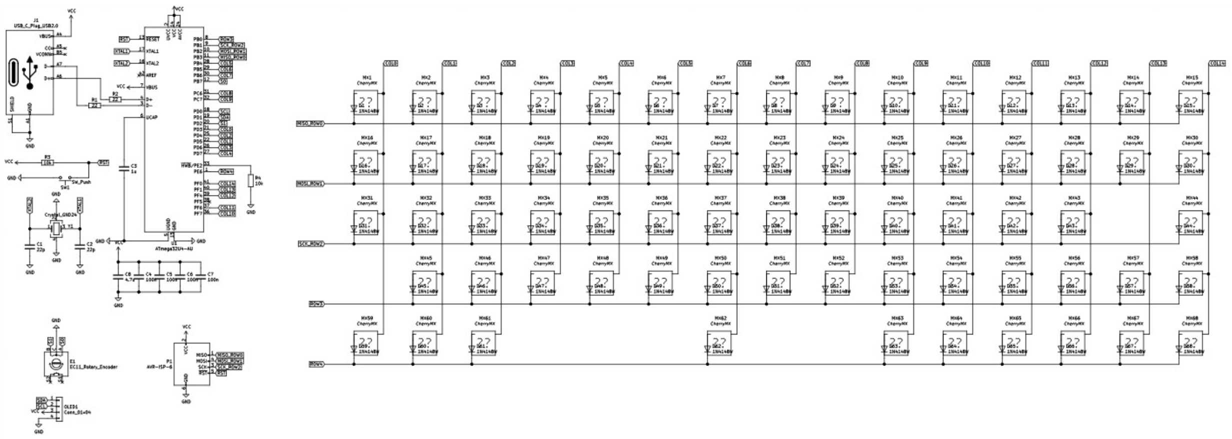


Fig. 009: mk01, Kimball Kaiser and Dirk Kaiser.

Fig. 010: mk01, Kimball Kaiser and Dirk Kaiser.

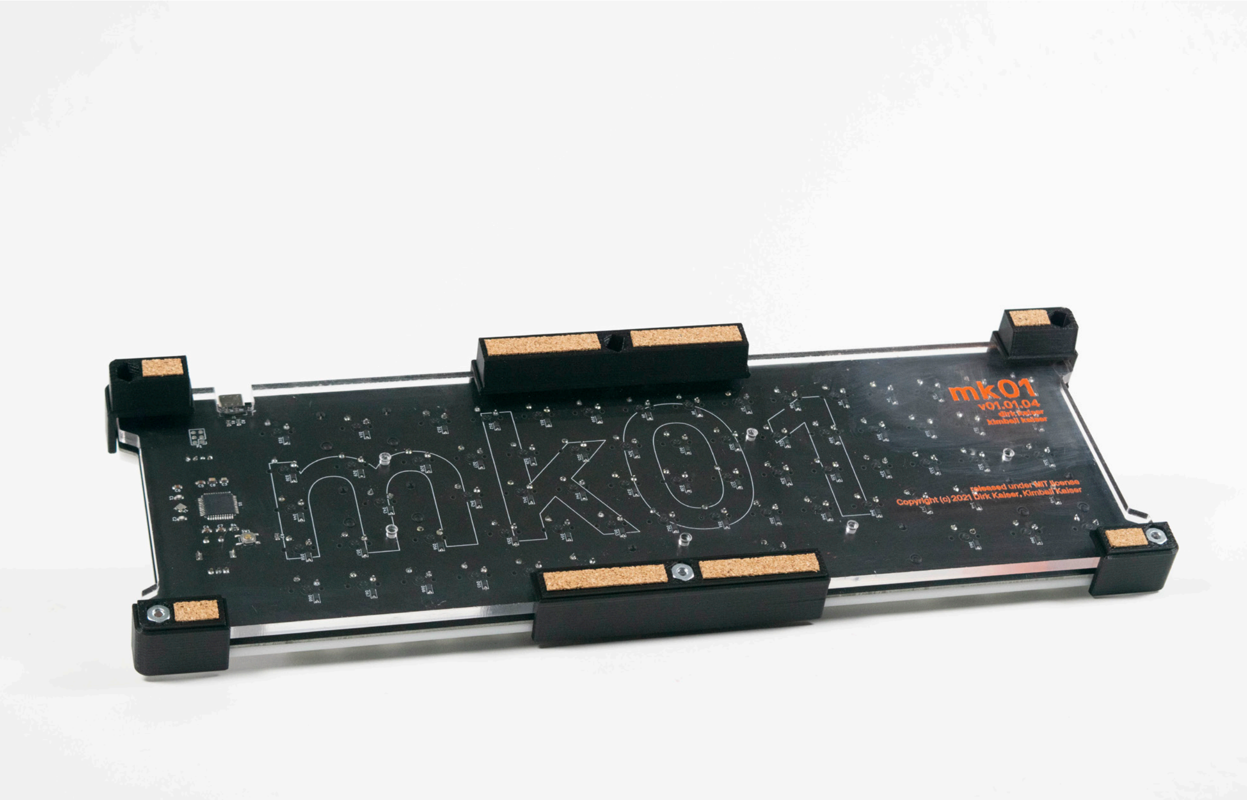


Fig. 011: mk01, Kimball Kaiser and Dirk Kaiser.

Fig. 012: mk01, Kimball Kaiser and Dirk Kaiser.

designed to be easily reproduced. The materials used in the case are flat and can be fabriced using various CNC cutting tools.

While it is easy to see how open source culture makes for available adaptations and modifications at this smaller scale, it is much more difficult to trace some of these same principles in architectural projects that claim to be of the same family. Architecture firstly is challenged by the much larger implied scale, amount of required financing, and complicated interaction between multiple trades, actors, and legalities. The parts, assemblies, and infrastructural requirements of architecture cannot all be 3D-printed or CNC milled. However, in 2011 the "Wikihouse" project was created as an "open source construction set with the aim to make it possible for anyone to design, 'print' and assemble low-cost, high- performance houses that are suited to individualized needs."[26]

The Wikihouse project also claims to also be conceived out of what is often called the third industrial revolution, where in CNC machines are assumed to be widely available to all. This rhetoric suggests that the 21st century factory is "anywhere," and that therefore the design team equipped with this distributed technology might be "anyone."[27] It is insisted that with these digital abilities (and the supposedly low barrier of entry), that non-expert users can design and share digital plans for houses that can be built and assembled by anyone. In the most utopian sense, the Wikihouse is an architecture project that would allow the larger masses to serve themselves with architecture, developing cities from the "ground up" rather than putting individuals at the mercy of architects working for only the most powerful and wealthy clients and developers.

While the Wikihouse's ambitions and goals are more than admirable, it is worth analyzing how truly open of a system it is. The Wikihouse project is described as a software plug-in that transforms "3-D models to cutting files in one click." The concept implies that a design created to the specific needs of an individual can easily be turned into a set of parts that are press fit together like a puzzle to build a structure without extra laborious planning.[28] The assembly style and strategy of specific pieces that snap together is also reminiscent of other snap fit projects that have happened within the realm of MIT, such as Lawrence Sass's Digitally Manufactured Housing for New Orleans, a project that displays the capabilities of using flat CNC milled parts for assemblies into 3-dimensional forms held together in friction fits.[29] However, because of the way these projects operate (but not against their ambitions) it is important to assess in what ways these projects are not truly "open."

Jose Sanchez in *Architecture for the Commons* brings into the discussion a helpful way to talk about assemblies through what he calls "holistic" or "non-holistic" sets. In this diagram, architectural assemblies will always lie somewhere between these two different types of "sets." Sanchez's analogy for the difference between the two "sets" is most accurately depicted through the use of commonly known toys. Holistic sets in this case, are defined as collections of parts defined by the whole, whereas non-holistic sets are characterized as sets of parts that have multiplicities of different configurations, redefining the "whole" as a state open to an actor.[30] The former is represented by a jigsaw puzzle, where each part fits in a certain place to make a predetermined whole image, and the latter is illustrated by the ubiquitous LEGO.[31] The LEGO here is defined as a set of parts that comes in a package to produce a suggested structure, yet can easily be disassembled, reconfigured, combined, and adapted into almost limitless results. This difference is key to understanding the limits of Wikihouse's "open" nature.

Setting aside the fact that CNC router technology at the scale of 4'x8' plywood still may not be as easily accessible as it is stated to be, considering it requires large investments in machinery and space, the snap fit methodology also makes for a series of fairly complex, unique parts with matching specific joints, which do not always match the claim of supposedly being open and easy for all. Beyond that, as a methodology, the fabrication system is inherently closed, and acts more as a determined set of jigsaw puzzle pieces to a predefined whole. Though the Wikihouse system can generate a variety of results in form and size, it does not lend itself to open modification as its parts are determined and generally singular in their purpose. So while the Wikihouse is a clever way to turn a stream of flat sheet material into a complicated 3D structure, through the course of fabrication and assembly it acts more as a closed platform, where "you get what you get" — meaning while it does generate a set of parts with specific

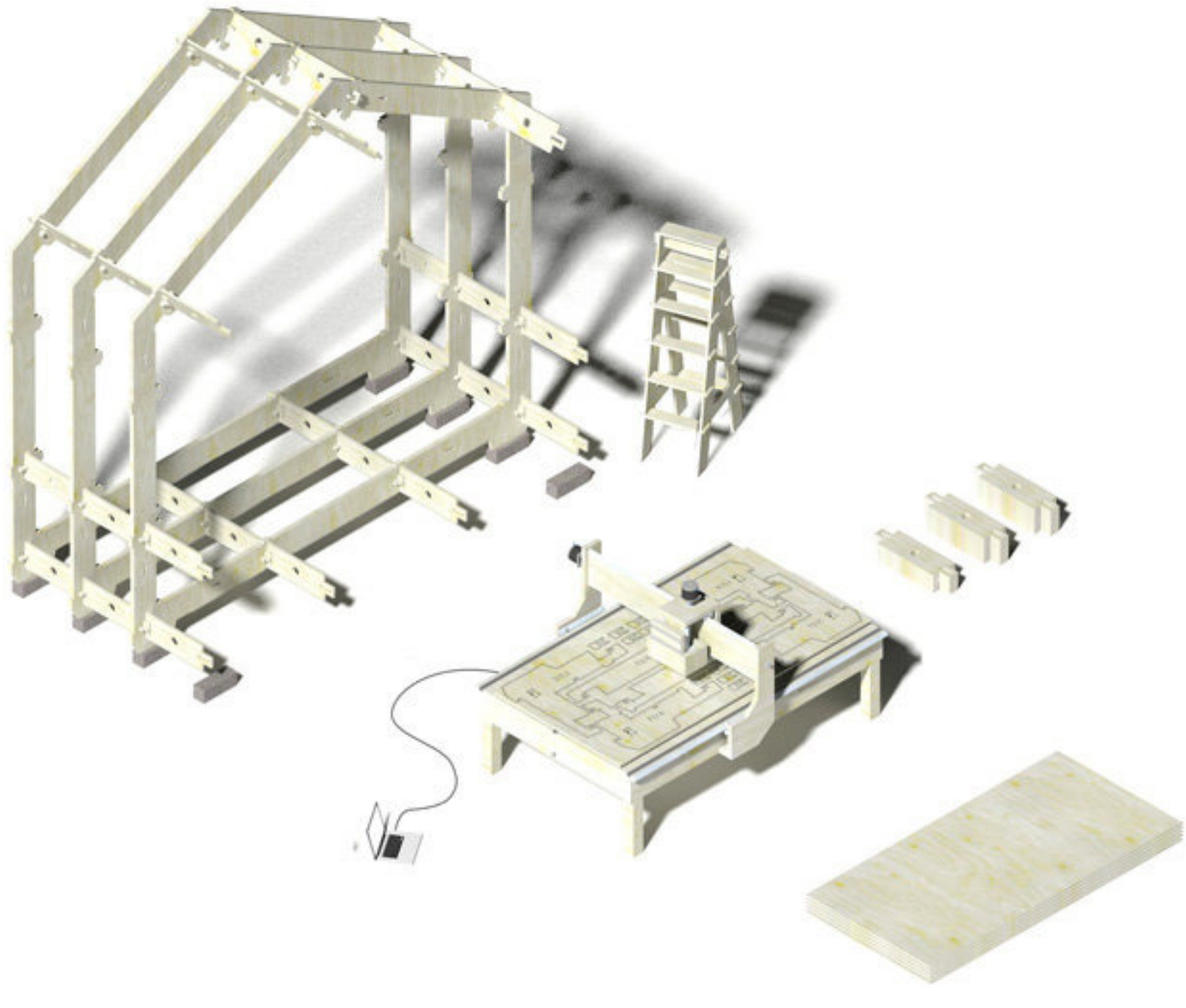


Fig. 013: Wikihouse. https://www.researchgate.net/figure/The-WikiHouse-building-parts-Wikiparts-Source-WikiHousecc_fig1_335507479

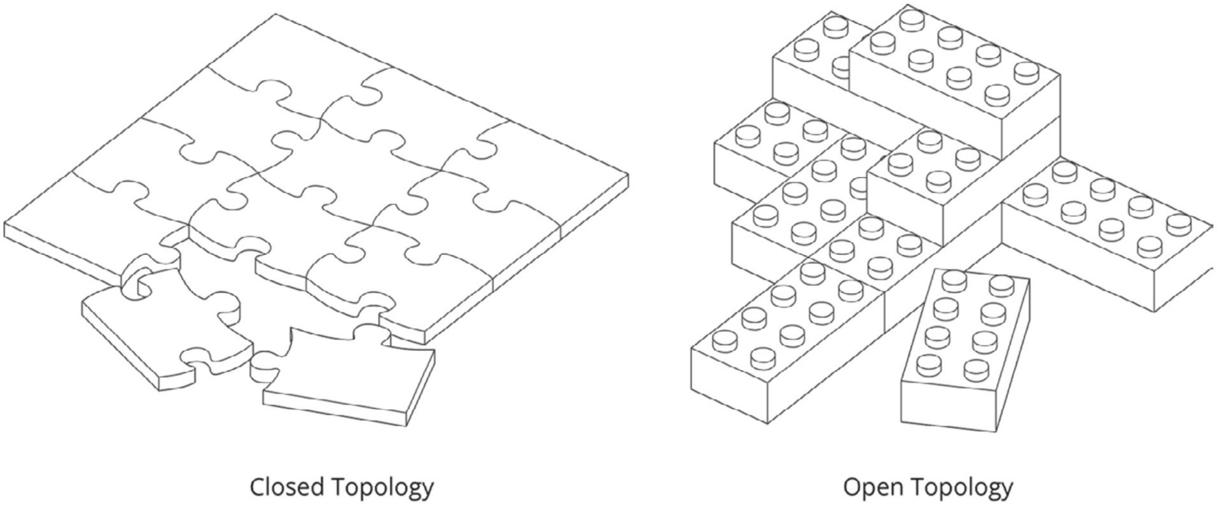


Fig. 014: Diagram for the differences between holistic and non-holistic sets, Jose Sanchez. "Architecture for the Commons." 2020.

uses that can be shared, it does not allow for the modification of the resulting parts or the conceptual process. Forking is thus not possible with a Wikihouse assembly.

In this binary, between the differing assemblies of architecture and its comparisons to toys, the non-holistic set (LEGO) is used as an argument for the self-defined Discrete group of architects. Such is Sanchez's introduction to the conceptual argument as a member of the said group. The Discrete methodology is founded in part on its opposition to the continuity of the Parametric design style, instead insisting on the considered arrangement of smaller units rather than piecing together complex developed surfaces that rely on the notions and capabilities of digital fabrication. The Discrete project is instead dependent on the repetition of the exact same part that has the capacity through its connections to be oriented and assembled in multiple orientations and positions.[32]

The whole Discrete paradigm breaks from the more recent tradition in digital fabrication that has spurred the discourse of mass customization. Mass customization, in this case, is the attempt to consider digital crafts as being free from the economies of repetition. In this mindset, bespoke pieces of digital craft no longer come with an extra cost. As Mario Carpo notably described in *The Alphabet and the Algorithm*, traditional fabrication processes using molds or jigs have their costs ameliorated by repetitive use, whereas digital fabrication tools can produce limitless variation at no extra cost.[33] Instead, the Discrete, as a reconsideration of the bare building blocks of architecture still argues for the economics of serialization and an economy of scale, not just for the sake of cost, but also for the possibilities of a truly distributed architecture that can be left open-ended. This not only refers to form but also as a mechanism for considering the social function of such a methodology that allows for actors to make multiple arrangements.[34] It is through this form of assembly based on repetitive parts that design as a development of patterns becomes more like an open platform and a place within a social system where a diversity of voices can participate.[35] This is not unlike open source projects where users decide what outcome is ultimately valuable on their own.

It is clear that in the field of architecture the negotiation between the most schematic design concepts and its smallest respective parts will be forever a project. From the modular projects of modernism to the more recent influence of the digital paradigm on fabrication and architectural components, the smallest parts are still worthy of consideration. Between the cracks of all these projects, *Parts-In-Progress* is an attempt to test a space that still exists somewhere between the larger, customized assemblies and smaller building blocks.

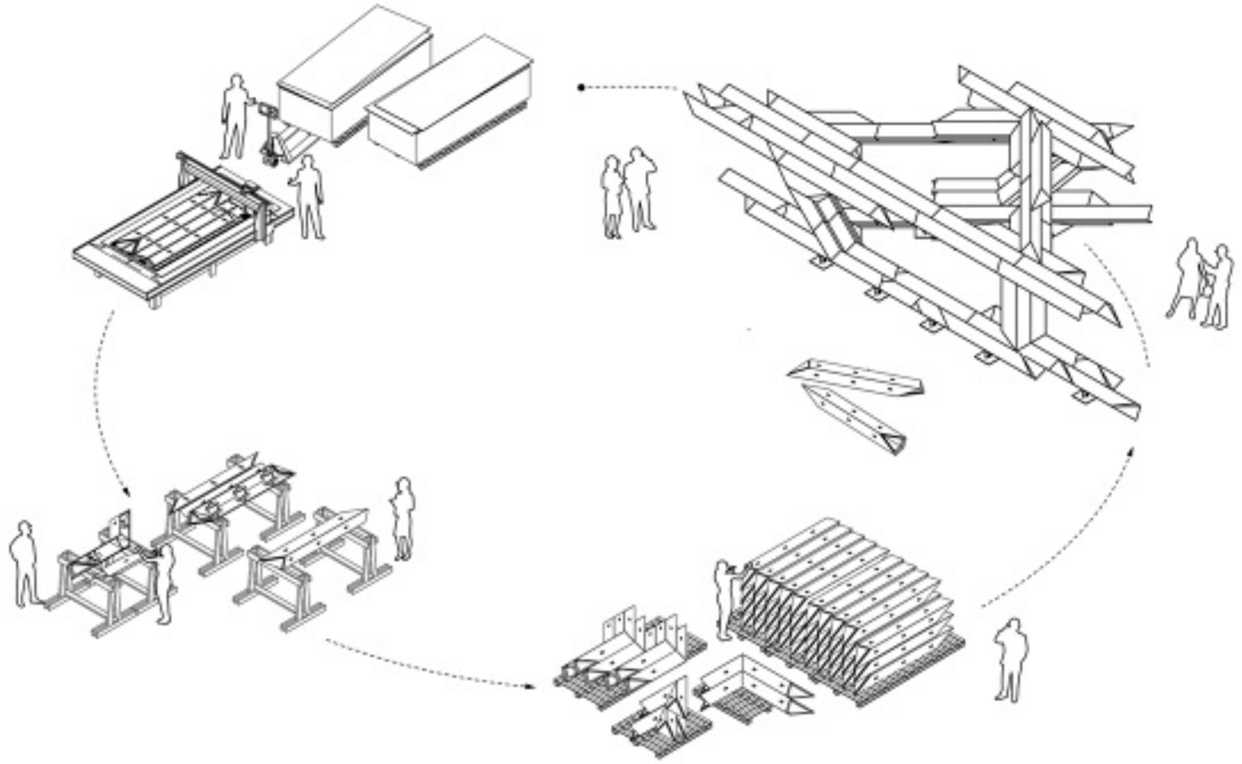


Fig. 015: Tallinn Architecture Biennale Pavilion, Gilles Retsin. https://www.retsin.org/Tallinn-Architecture-Biennale-Pavilion.

Fig. 016: Tallinn Architecture Biennale Pavilion, Gilles Retsin. https://www.retsin.org/Tallinn-Architecture-Biennale-Pavilion.

PART IV

Conceptual Positioning

PART IV
Conceptual Positioning

Within the discussions pertinent to this project, the relevant discourse and projects related to attitudes around fabrication, assembly, and strategies of recycling/reuse vs disassembly can be separated into families to further target the conceptual position of *Parts-In-Progress* as a working set of ideals.

Amongst many architectural projects working through the reorienting of building detritus and construction waste are examples like Certain Measure's "Mine the Scrap," which in order to turn waste into a resource, takes computer vision to sort a hypothetical waste stream of sheet material to find the most optimal pieces for creating a new form. As a project invested in waste materials, Mine the Scrap "develops a new vocabulary of design that is fundamentally informed by resources."[36]

On the other end of spectrum of projects also informed by material resources, Stock-a-Studio's ongoing "Someparts" could be noted as an alternate conversation on the same plane.[37] In this kit of parts, elements come from a catalogue and design is relegated to a curated group of available proprietary parts. These parts are fully intended to participate in a circular economy of materials connected only by bolts. While these parts are made for construction, they are equally made for disassembly and reuse. Someparts conceptually represents the most full scale principles of the erector set, where various metal beams with regularly spaced holes can be assembled together by large audiences with just nuts and bolts.

While both projects are engaged with the life cycles and sourcing

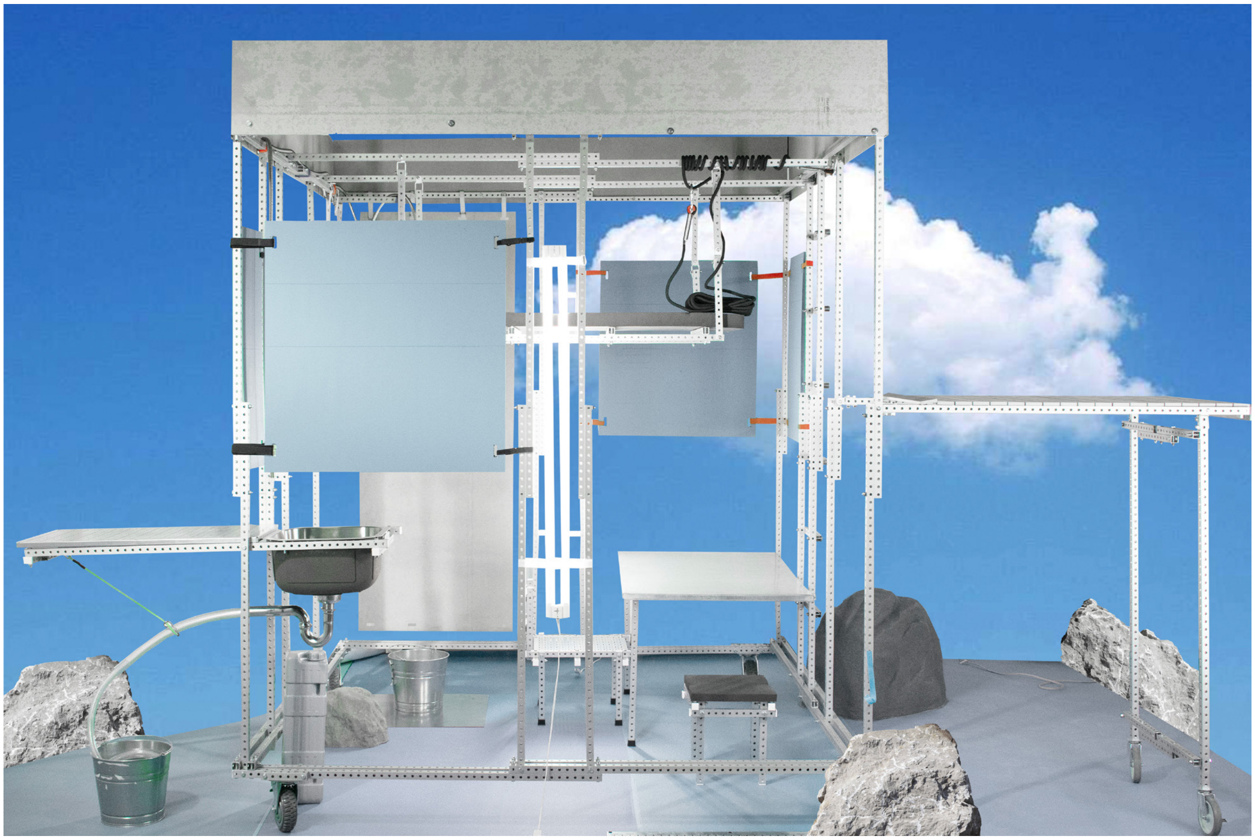


Fig. 017 (Top): Mine the Scrap, Certain Measures. https://certainmeasures.com/MTS_003.
Fig. 018 (Bottom): Someparts, Stock-a-Studio. https://stockastudio.com/

Fig. 019: Axis of Considered Material Usage, by author.

of materials, if represented as separate poles, they can be laid out on a diagrammatic axis to describe a range of architectural strategies, defined here as the "Considered Material Usage" axis. It is also important to note that for the positioning of *Parts-In-Progress*, this axis is also generally matched by a difference in computational and fabrication strategies. On the left pole, projects tend to be more computationally invested. In the case of Mine the Scrap, the project is entirely based on the ability for computer vision to sort through data (in this case of this project, sheet material). Digital fabrication technology is then applied to make a limitless amount of new parts and unique cut patterns. On the other hand, projects on the right, where standardized connections are already ingrained into the parts, represent a much lighter computational and fabrication process. All that is needed, in this case, is a wrench.

To add an additional axis in the perpendicular direction to define the argument of *Parts-In-Progress*, there is the discussion of arrangement and assembly. This vertical axis is defined as the axis of "3D Composition and Assembly Logic." This upper pole is defined by assemblies with more customization or abnormalities. Towards the bottom end, assemblies are more standardized, cartesian, and modular.

With this second axis introduced, the project locations of Mine the Scrap versus Someparts, drift apart even further, as the former is an assembly of unique parts with unique fits that resist replication, while the latter is entirely comprised of standard connections. To further illustrate

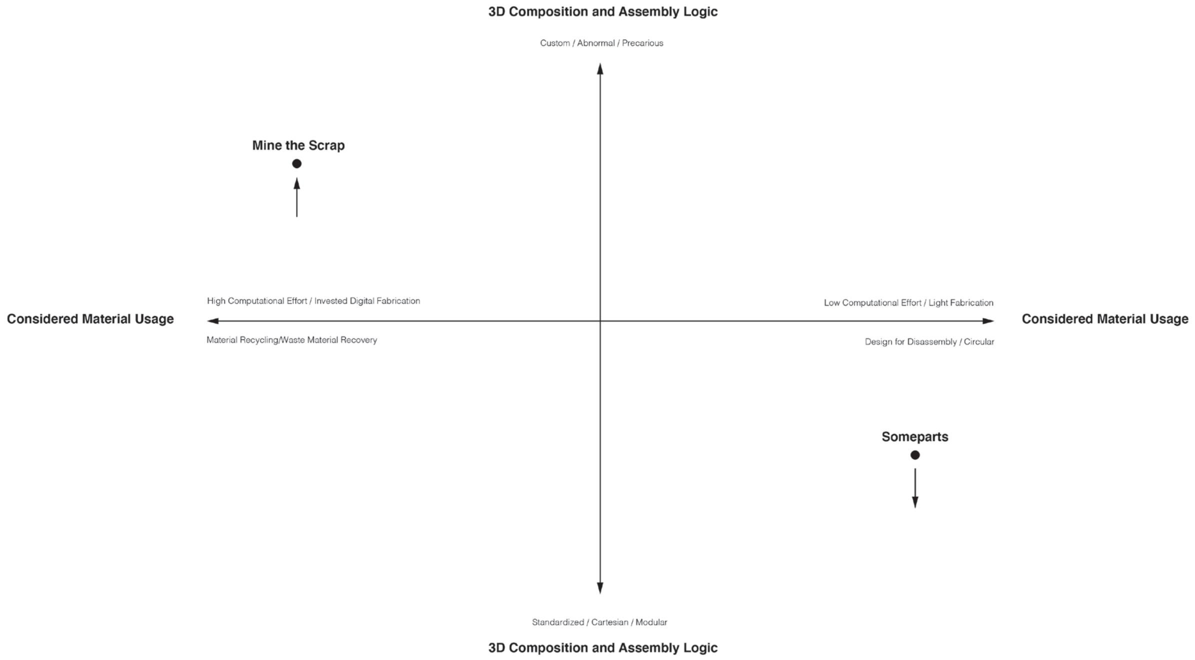


Fig. 020: Axis of 3D Composition and Assembly Logic, by author.

the variances in assembly and examples closer to this vertical axis, the introduction of a few projects is worthwhile.

“Log Knot” by HANNAH is plotted along the upper half of the vertical axis. This project uses unique, discarded logs, each connected by a uniquely fabricated joint that is CNC milled by a robot arm. As its name suggests, the resulting installation is a wondrous bundle of logs in anything but a standardized form with pieces belonging to singularly defined positions by way of entirely customized joints.[38]

On the lower end of the axis, the most notable construction system at the architectural scale would be projects involving scaffolding, or scaffolding systems themselves. As assemblies, scaffolding is inherently standardized. All parts are made to conform to certain compatible dimensions and all connections are standardized. These systems are designed to work within a cartesian space, and are intended to be reusable using impermanent connections that can be swapped or fit into multiple places across the larger standardized assembly.

Amongst this conceptual mapping, *Parts-In-Progress* is meant to be situated in a sliding zone at the intersection of these axes. The project is positioned somewhere in the middle on the horizontal axis through its mix of digital fabrication and analog fabrication that represents a concept of “middle tech.” In the vertical axis, a sliding range of assemblies that can range from relatively standard to more customized and abnormal constructions are possible through the constraints of *Parts-In-Progress*, thus

Fig. 021 (Top): Log Knot, HANNAH. https://www.hannah-office.org/work/knot.
Fig. 022 (Bottom): Open Air Theatre, Colab-19. Photography by Alberto Roa. https://www.dezeen.com/2021/01/19/la-concordia-amphitheatre-colab-19-bogota-architecture/

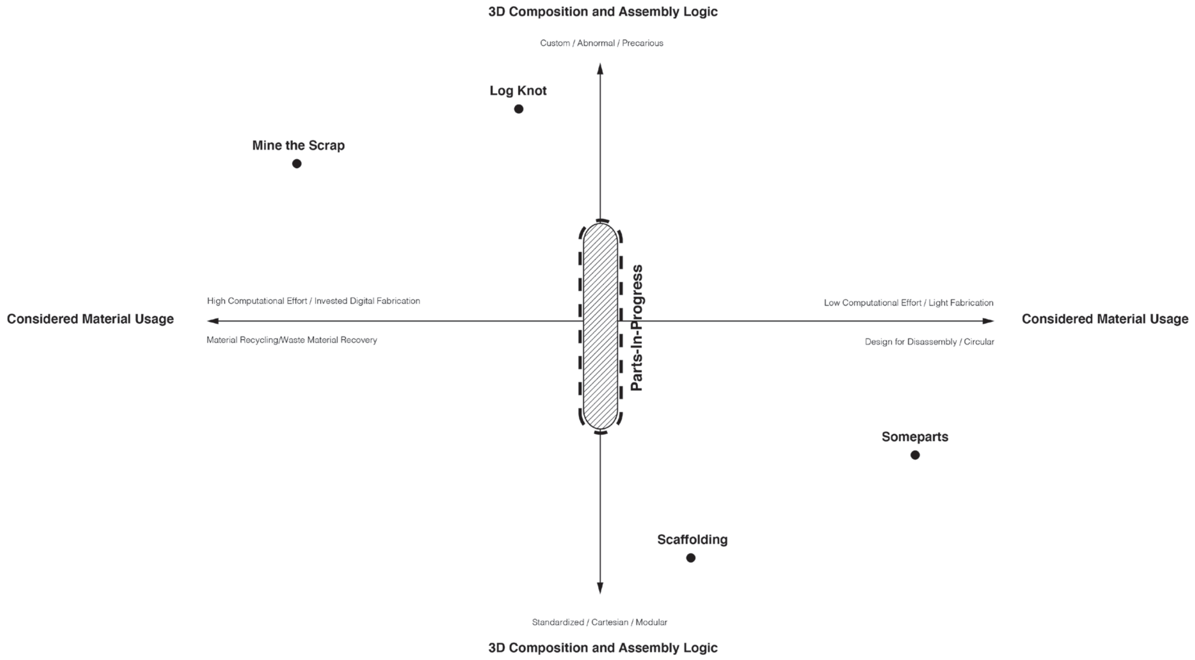


Fig. 023: Parts-In-Progress “conceptual zone,” by author.

located along a zone in the vertical axis. To further describe the ambitions of this zone a description and argument centered around a few points is to follow.

Firstly, the parts of this project are meant to remain as open as possible. This is to of course encourage disassembly and reuse, but also to allow for a design of parts that makes them useable for larger, varied contexts. The conceptual attitude of the parts in this project are definitely not that of the unique, singular parts of the press fit project. Instead, parts are meant to be open to adaptation and multiple configurations at the scale of their combined assembly, but at the level of the digital file as well.

Secondly, the parts of this project are meant to address the complexities of architectural assembly. The Discrete project is also whole-heartedly invested in an open set of parts, and often in projects of architects like Gilles Retsin, the parts have a friendly, simplistic look to them that assuredly conceals their complexities. For example, these parts with multiple possible orientations and positions most likely contain elaborate moment connections. Not only this, but each part is still composed itself of several digitally fabricated pieces. The parts of this project are *also* the tools of fabrication, embedded with the knowledge of fabrication and assembly. These sharable parts are therefore also simple jigs, instrumental in creating different assemblies, making *Parts-In-Progress* a “middle tech” project.

The parts of this project are also meant to address the economics of parts. While the Discrete project is interested in making an economic argument around serialization, and the press fit project leans on the supposed "costless" abilities of digital fabrication itself, *Parts-In-Progress* is about taking an alternative approach to this question. Instead of creating a serialized sophisticated part, or taking raw materials and manipulating them into specific "jigsaw puzzle pieces," *Parts-In-Progress* argues for tapping into the existing building material supply chain and using the given dimensions of stock materials as the building blocks of this project. Instead of trying to justify the reproduction of the same designed part, why not already use the existing part given by the logistics network? In this case, *Parts-In-Progress* is all about hijacking the economics of reproduced parts straight from Home Depot, using dimensional lumber in its unadulterated form.

Lastly, as assembly strategies, the collections of *Parts-In-Progress* deals with a set of connectors as specific constraints. However, these constraints are engineered in such a way to produce a variable amount of unpredictable-like outcomes. In the context of this project, this is defined as "calculated precarity," a concept to be further described throughout the next chapters with the design and fabrication project of testing this thesis.

PART V

Parts-In-Progress

PART V
Parts-In-Progress

Amongst the building toy comparisons, *Parts-In-Progress* fits better into a conceptual third category when compared to the groups of "jigsaw puzzle" and "LEGO brick". A more appropriate toy for this project would be the K'Nex, a construction toy first introduced in 1992, that operates as a non-holistic set of rods and connectors that allows for attachments in multiple arrangements and directions in space.[39] However, as a K'Nex, *Parts-In-Progress* would be a version that is capable of connecting to different stock forms of planes, sticks, and pipe geometries at a series of eccentric angles.

In the fabrication and design project of experimenting with these conceptual ideas, three parts were used throughout a series of designed assemblies. These parts were 3d-printed as serialized parts. All parts are open to working with different dimensions in standard material forms. One part was made for "stick" geometries (studs), another for planar geometries (boards), and a third for rods (wooden dowels). All these parts are meant to be re-usable and reconfigurable through different assemblies, hence the name *Parts-In-Progress*.

Not only are these parts considered reusable pieces through varied assemblies, they are meant to be easily shareable strategies via their production from digital files. These techniques have been developed so that these parts can be modified to other dimensional materials and used in the same assemblies. It is equally important to consider that these strategies are adaptable to variations in different material settings or different stock

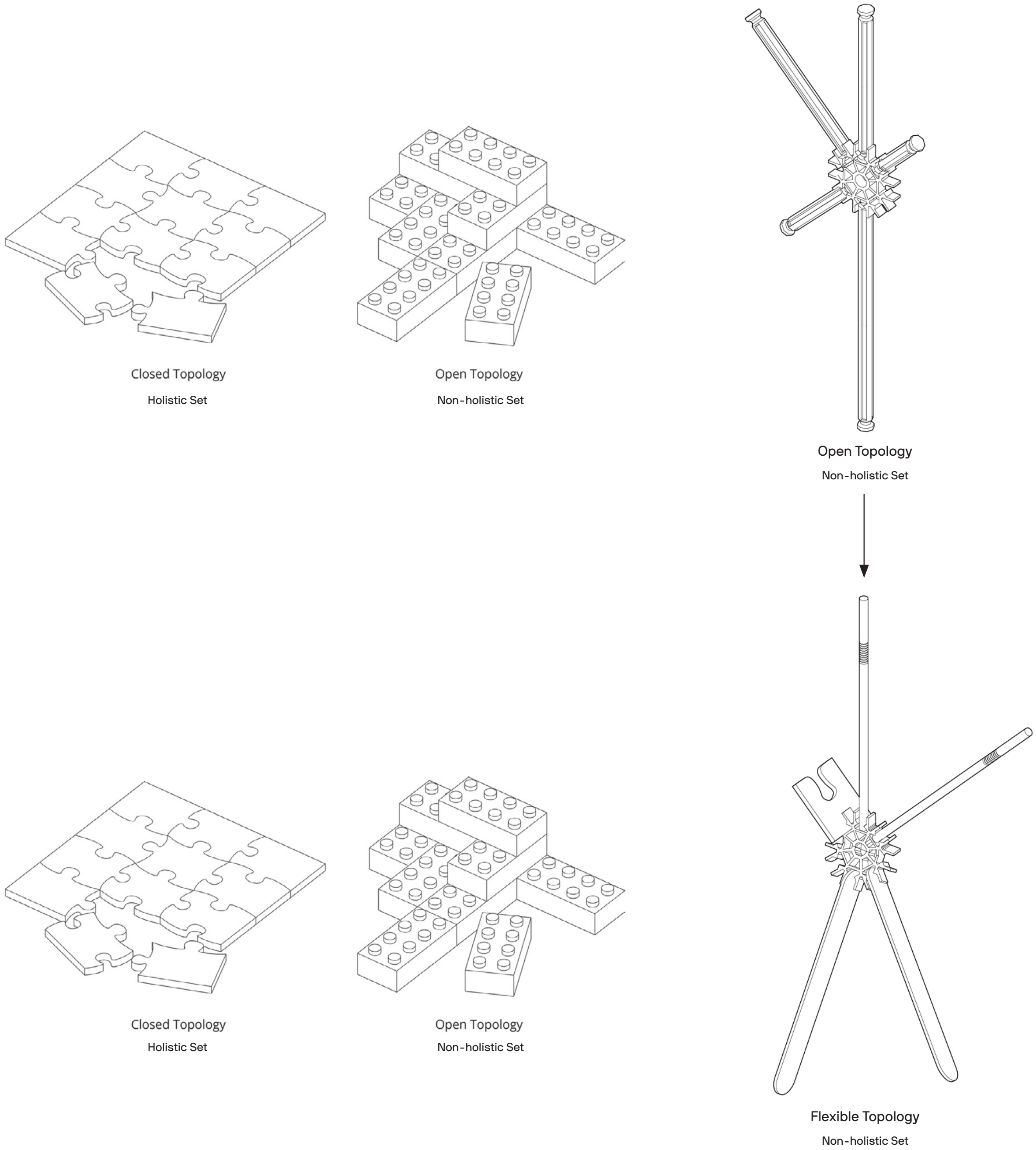


Fig. 024: (Left) Diagram by Jose Sanchez, (Right) Diagram by author.

streams as well. In this manner, the part itself is a forever work-in-progress.

While these parts are all components of their respective assemblies, as per the strategy of "middle tech," each part is an active participant in the fabrication of the joints that fasten said assemblies together. Therefore, each part acts independently as a drill guide for creating a hole at a specific angle, making the only outside equipment needed for fabrication a standard drill. These specific angles then become the adjustable constraints for the connections of different parts to one another.

Through these drilled holes constrained by a specific set of angles, these parts then allow for a number of different arrangements through a bolted connection, which are standardized per part, yet unpredictable and more open in their connections to other parts. This means in-plane and out-of-plane, a variety of connections to the same part are possible in several different orientations. These connections can also be made through different standard material forms, creating connections from rod-to-rod versus rod-to-stick for example.

Lastly, manipulations to standard materials are also done as gently as possible. This is done to preserve the dimensional materials with modifications only happening at the ends of individual members. Not only does this minimize the efforts spent manipulating stock materials, it also saves materials for other uses in case they entirely leave an assembly without their constituent parts.

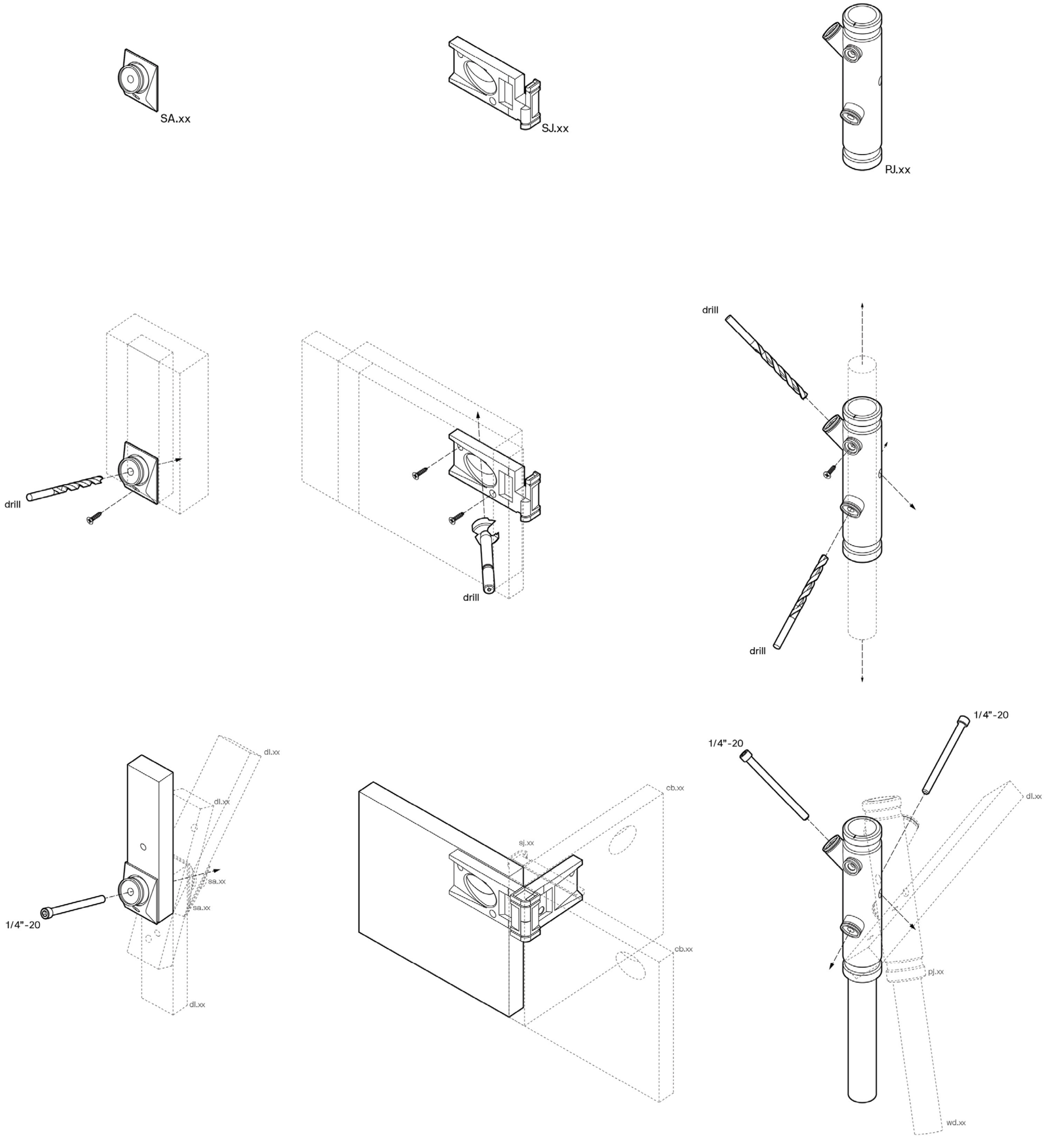
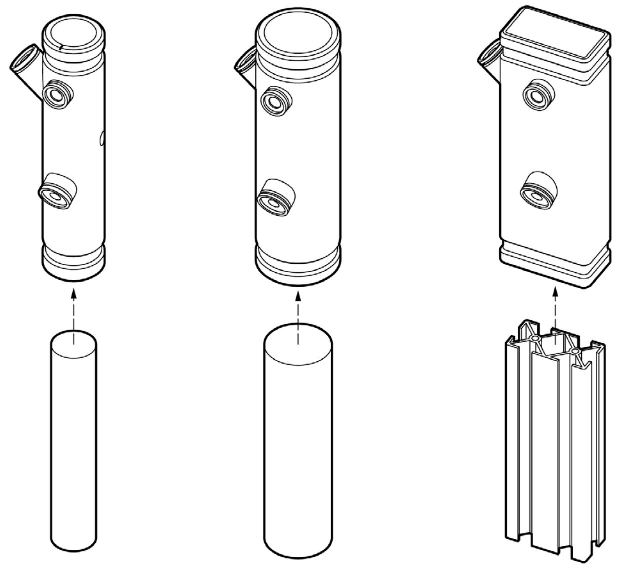


Fig. 025: Parts-In-Progress, by author.



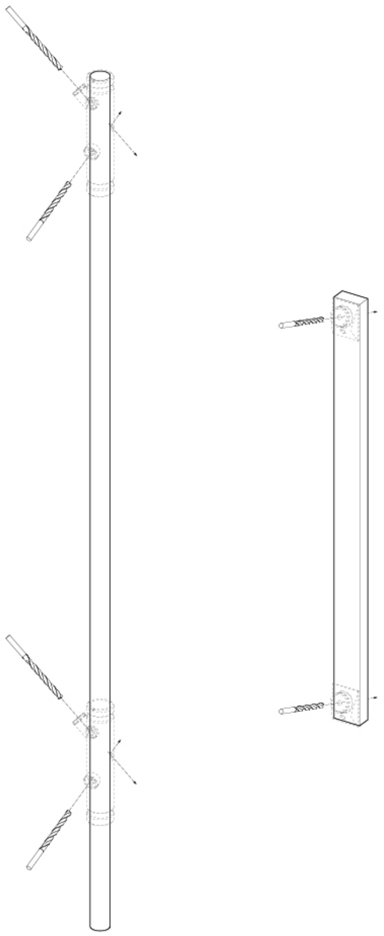


Fig. 026 (Top): Adaptable Parts-In-Progress, by author. Fig. 027 (Bottom): Manipulations at Ends of Members, by author.

PART VI

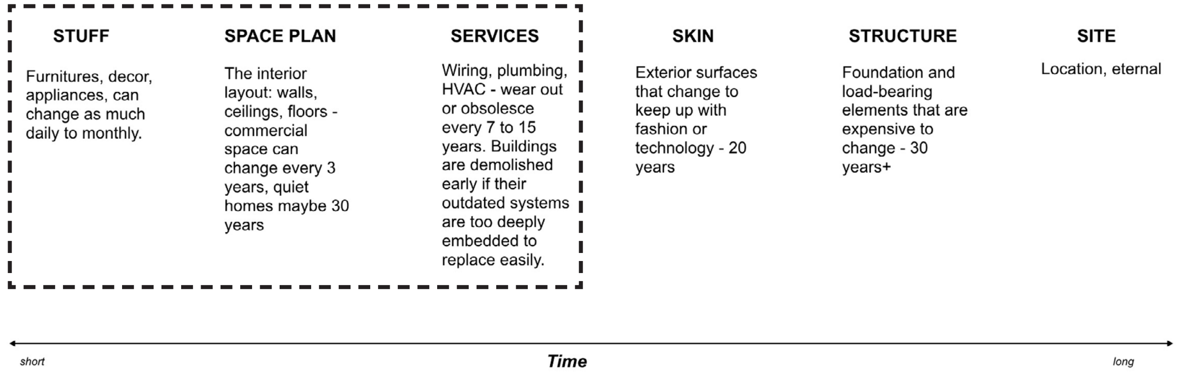
Setting

PART VI
Setting

In terms of finding the appropriate area to test some of the concepts contained within *Parts-In-Progress*, there were many aspects of an architectural scenario to consider in turning this project from a set of ideas into a physical prototype. Stewart Brand's *How Buildings Learn* considers the life cycle of buildings and what happens to buildings after they are built, providing a reference point for thinking through this project at the architectural scale. The book introduces a concept called "shearing layers," which essentially breaks down building components by order of necessary replacement when consulting the entire life cycle of a building.[40]

Within considering the most productive areas to test a hypothesis within the span of one academic semester, it is the layers of "stuff", "space plan", and "services" (and essentially the walls that might contain "services") that were the most appropriate for testing a fabrication and design project. These components are shorter in their time scales of replacement, creating scenarios where disassembly and adaptation is the most fitting solution. Elements like structure are the longest lasting elements of a building, whereas in contrast interiors are more frequently reconfigured and renovated. Furniture and interior layouts that contain the necessary infrastructural services of architecture within their walls are often subject to these changes.

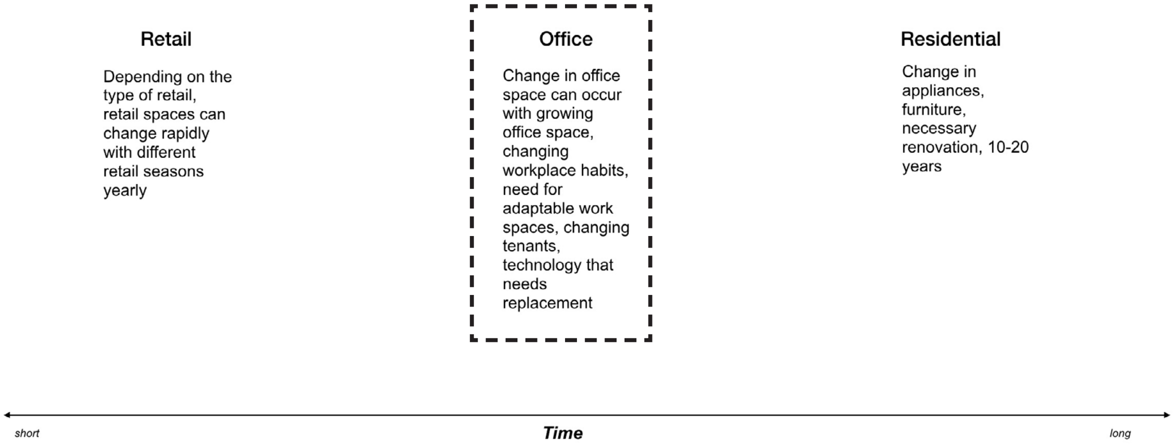
In addition to the consideration of physical elements, the programmatic situations that might be the most appropriate for testing on a similar timeline were also considered. Changing and adapting architectural interiors open up a range of optimal potential sites for hypothetical assemblies. Retail settings often have the quickest turnover for modifications to space layouts, in many cases taking place on a seasonal basis. On the other hand, programming such as residential spaces can be slower on the time scale. Even if done frequently, changes happen with larger renovations every few years. Therefore, office space as an option was deemed an appropriate location to test some of this work because of the way working environments can change relatively quickly with the growth of companies, the changing of tenants, shifting workplace habits, and perhaps most evidently right now, our changing work environments due to the Covid-19 pandemic.



STUFF	SPACE PLAN	SERVICES	SKIN	STRUCTURE	SITE
Furnitures, decor, appliances, can change as much daily to monthly.	The interior layout: walls, ceilings, floors - commercial space can change every 3 years, quiet homes maybe 30 years	Wiring, plumbing, HVAC - wear out or obsolesce every 7 to 15 years. Buildings are demolished early if their outdated systems are too deeply embedded to replace easily.	Exterior surfaces that change to keep up with fashion or technology - 20 years	Foundation and load-bearing elements that are expensive to change - 30 years+	Location, eternal

from Stewart Brand's *How Building's Learn*

Fig. 028: Appropriate Layers, by author.



Retail

Depending on the type of retail, retail spaces can change rapidly with different retail seasons yearly

Office

Change in office space can occur with growing office space, changing workplace habits, need for adaptable work spaces, changing tenants, technology that needs replacement

Residential

Change in appliances, furniture, necessary renovation, 10-20 years

Fig. 029: Appropriate Program, by author.

PART VII

Prototypes

PART VII
Prototypes

As for the design and fabrication project, a wall or partition that can contain the services or be part of an interior layout plan, and a set of corresponding furniture were designed. Additionally, to keep with the original goals of the design project, all prototypes are made of the same set of materials and have corresponding parts, as they can be disassembled and reassembled in different ways. The stock materials used in the project are commonly available and are 1”x8” common boards, 1”x2” strip boards, 2”x4” studs, and 1” diameter round wood dowels. These materials are used only in combination with the custom parts of this project, ratchet straps, and standard 1/4”-20 hardware. In accordance with the parameters of the design project, all materials are used at standard sizes, meaning if materials are cut, everything is cut to a 2’ divisible length — matching the interval of lengths in which standard dimensional lumber is produced.

As previously illustrated by the possibilities of varied connections, these following assemblies are designed in options that appear more standard while still possessing the ability to be rearranged in varied orientations. These assemblies then can also be morphed into more open and irregular compositions. This variation then in turn makes for more open assemblies and customizable abnormalities, which can be tuned to different settings and different use cases, demonstrating the opportunities that arise from “calculated precarity.”

Amongst this sliding scale of “calculated precarity,” the designed prototypes also display the possibilities of moving from more rectilinear

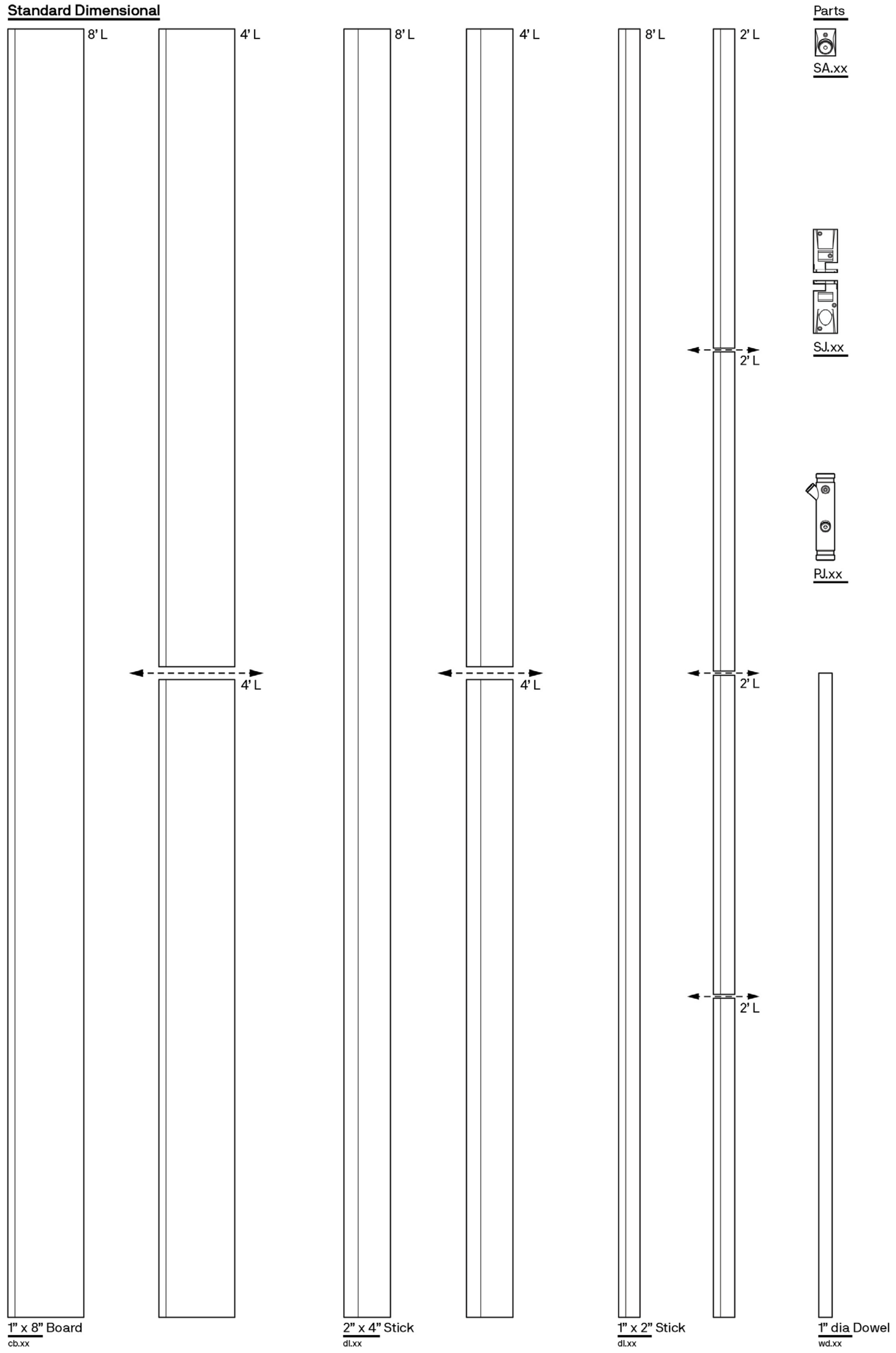


Fig. 030: Dimensional Lumber Sizes, by author.

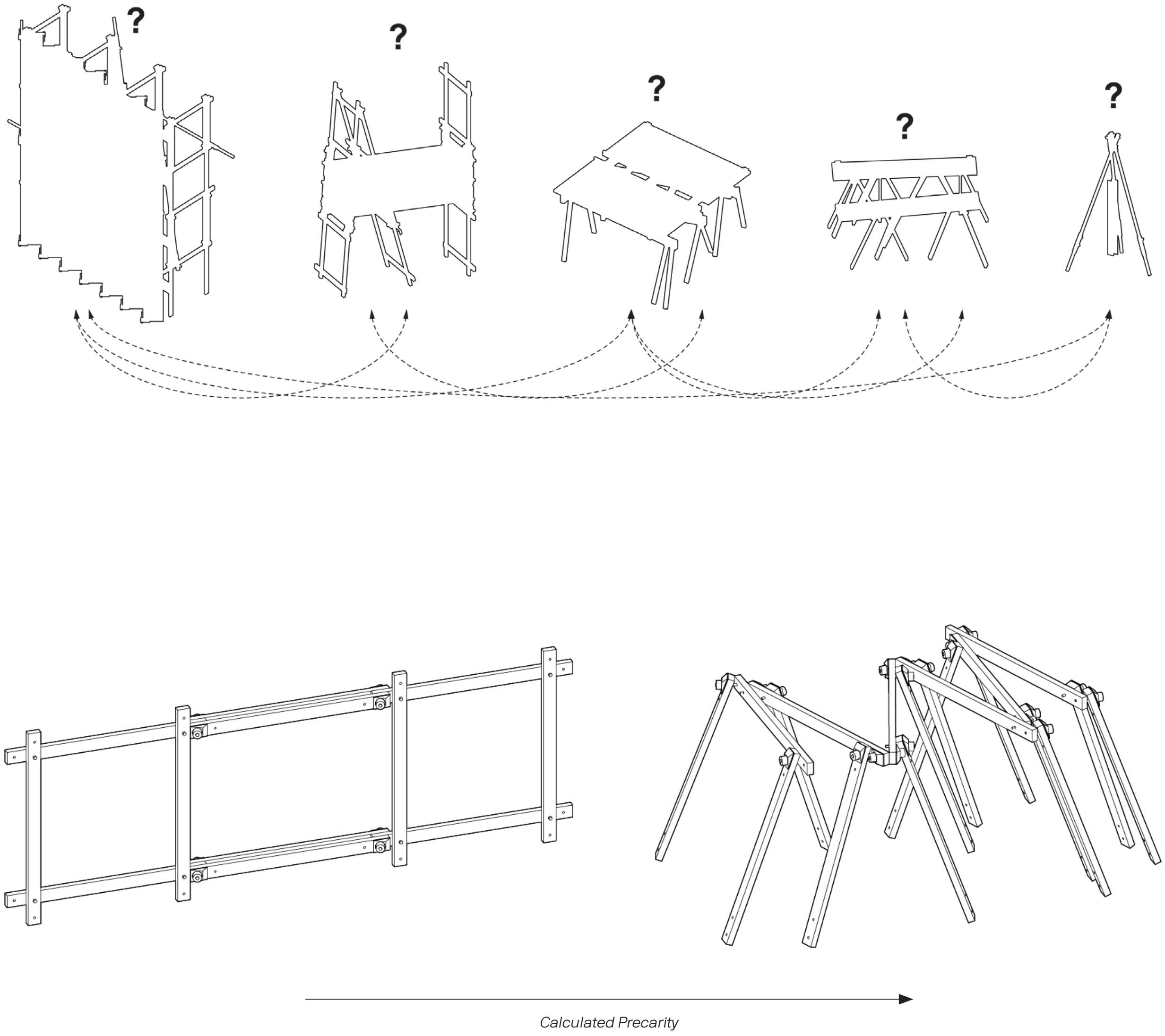
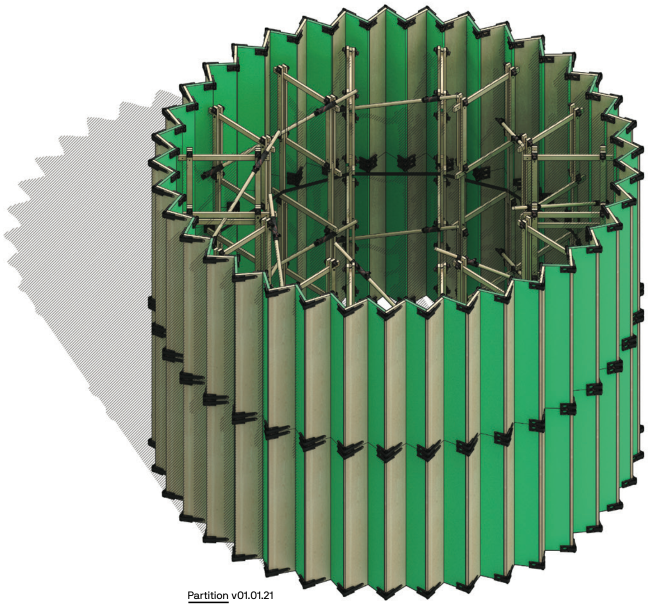


Fig. 031 (Top): Prototypes from the Same Parts, by author. Fig. 031 (Bottom): Calculated Precarity, by author.

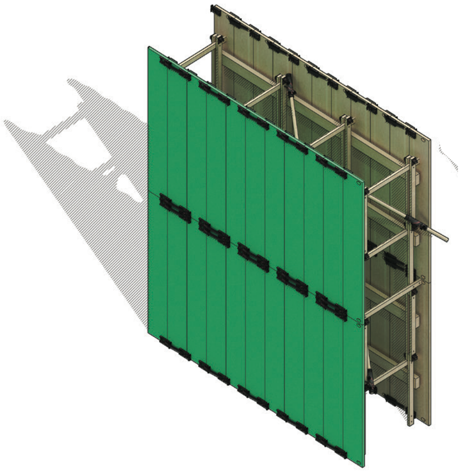
geometries to curvilinear geometries in layout. As actual fabricated examples of these designs, the prototypes are simply one of the designed options.

Walls

A straight section was fabricated out of a set of partitions that could be arranged in both linear geometries and curvilinear geometries. The smallest parts are 2 foot lengths of 1”x2” pieces, that can be combined to make for longer members in a more standard assembly, using dowels that are arranged through the structure to act as eccentric cross bracing. The zig-zag face of the wall is made from common boards that are ratchet-strapped to the structure. Everything can be disassembled.



Partition v01.01.21

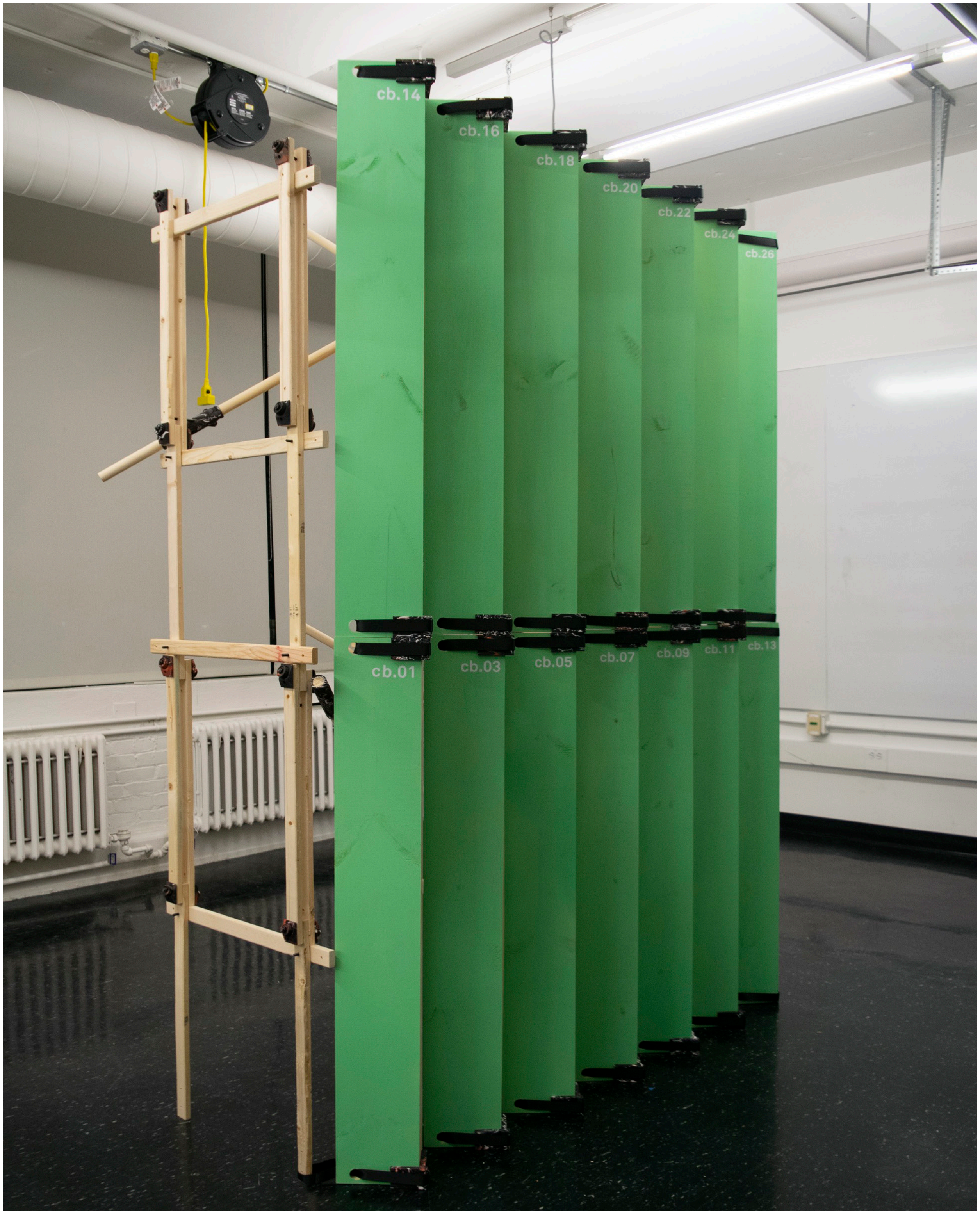


Partition v01.01.03

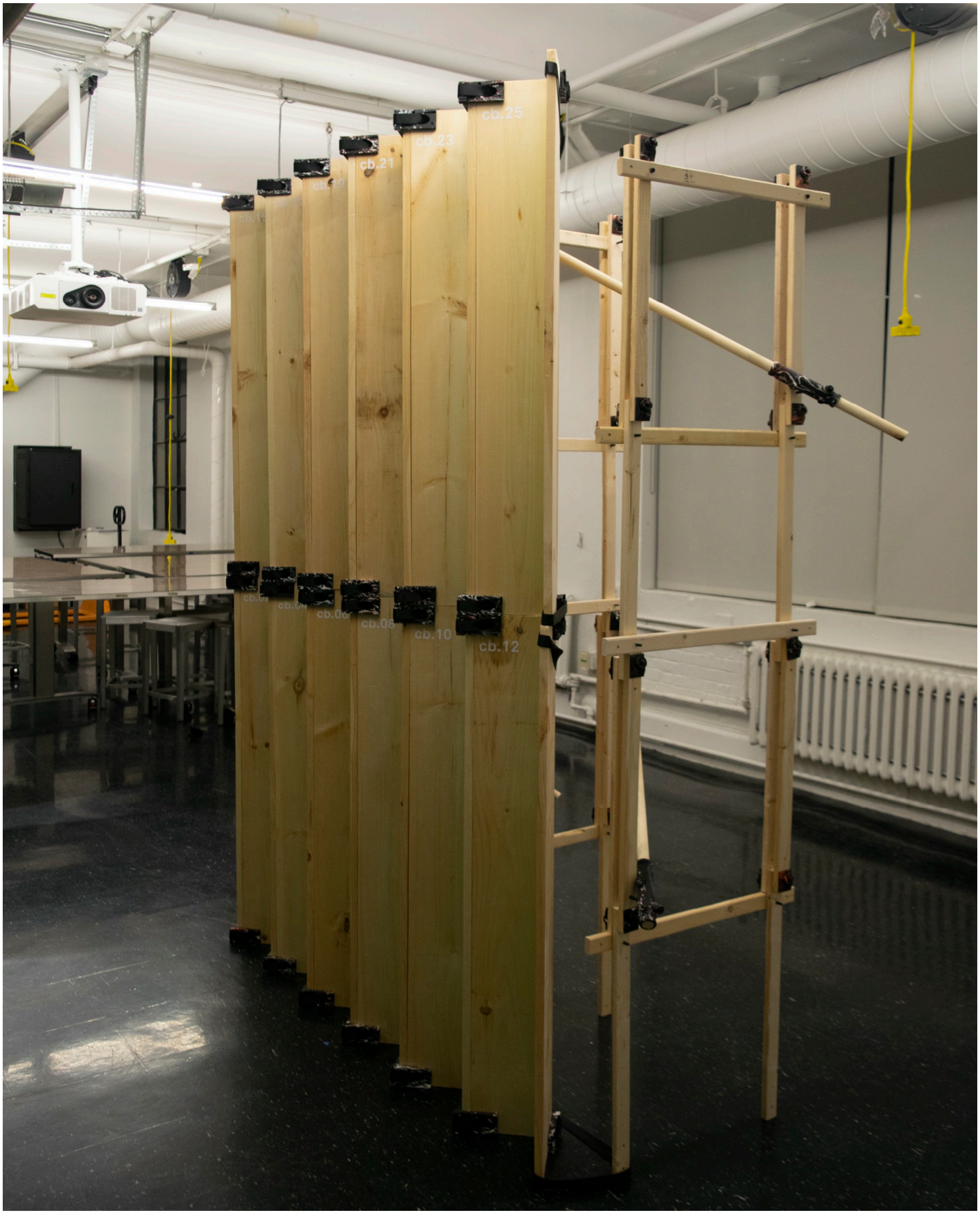
Partition v01.01.06

Fig. 032: Walls, by author.

Wall, by author.



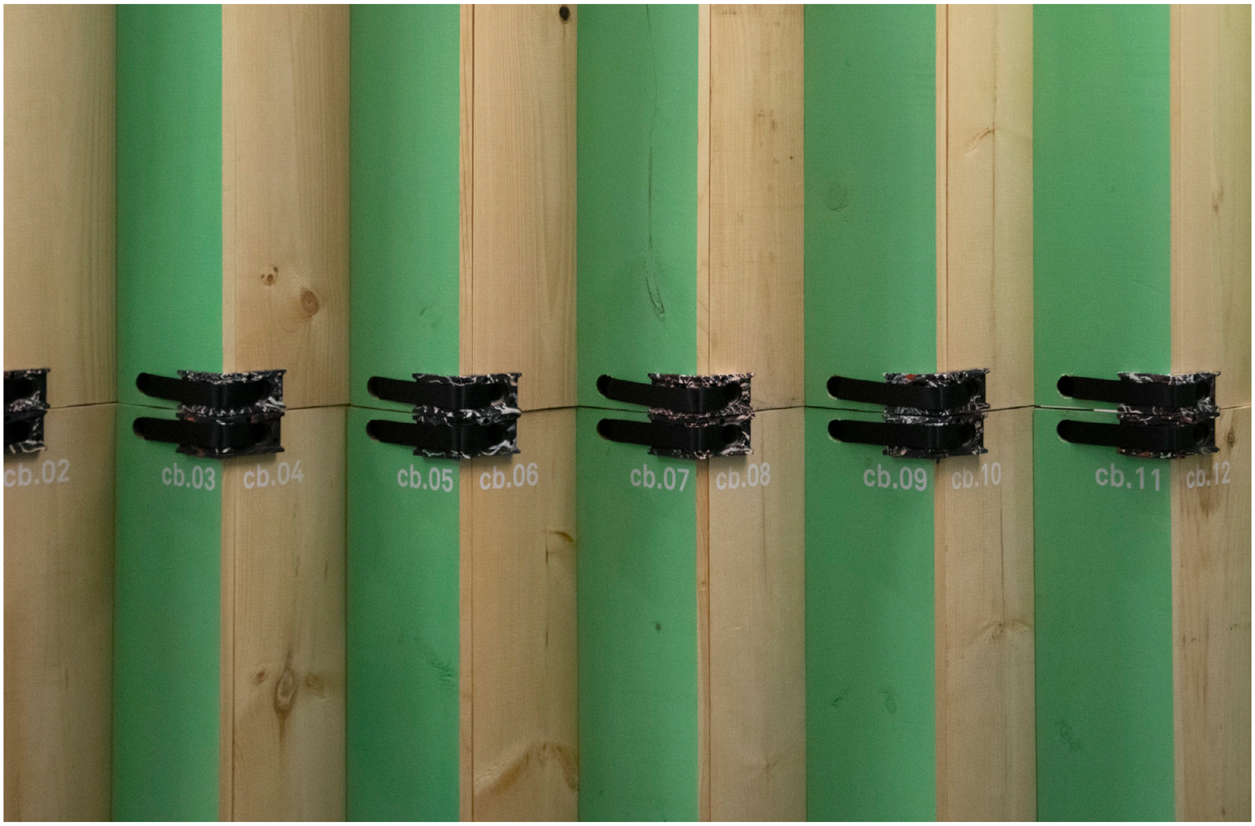
Wall, by author.



Wall, by author.

Wall, by author.

Wall, by author.



Wall, by author.

Wall, by author.

Wall, by author.

Wall, by author.

Lamps

This series of lamps is assembled from the opportunities of the disassembled wall, maintaining the specific relationships from the previous cross bracing. When these rods are reconfigured, a set of reciprocal frames can be assembled. These reciprocal frames come in different leaning variations. Everything can be disassembled.

Lamp v01.02.01

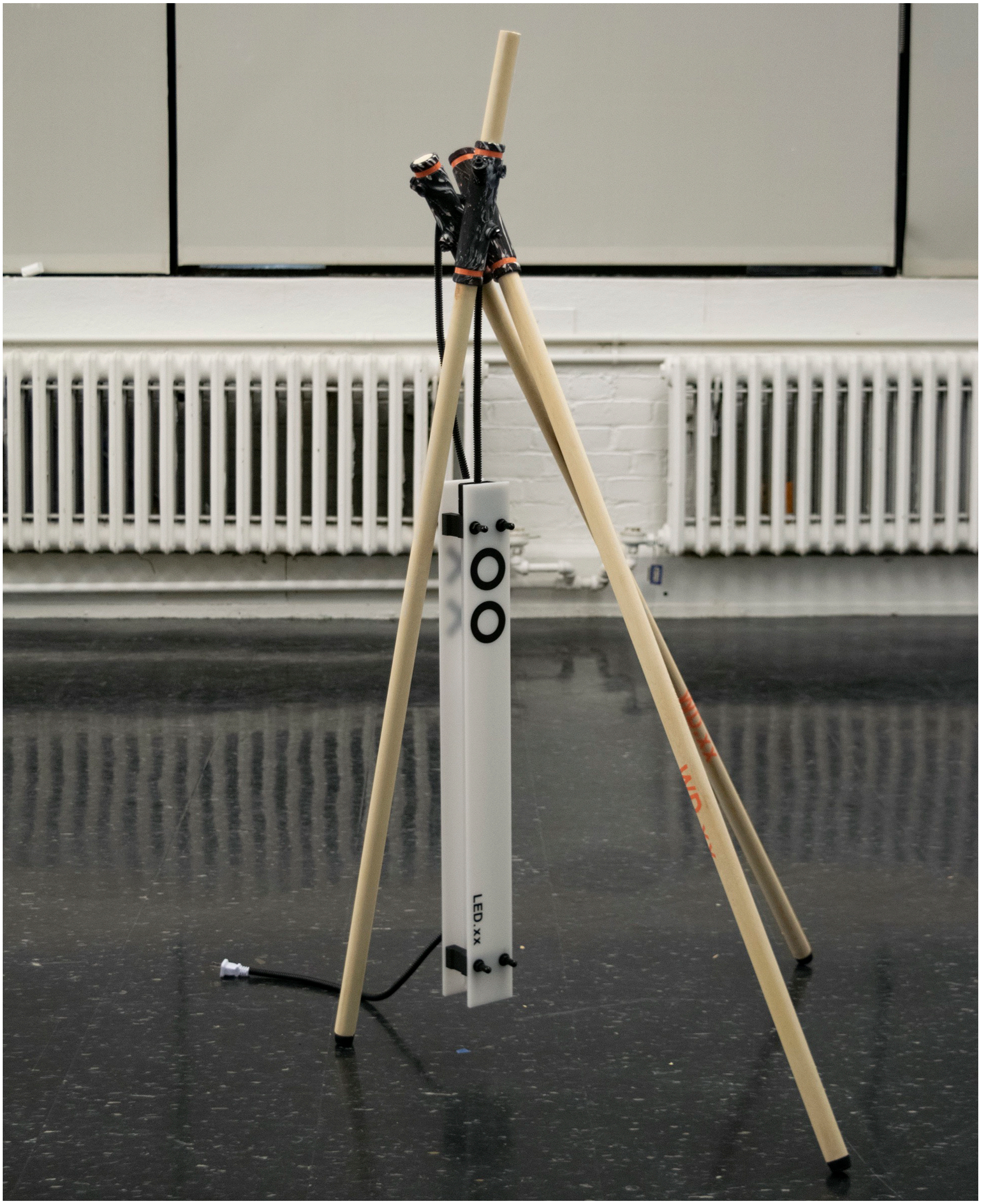
Lamp v01.02.02

Lamp v01.02.03

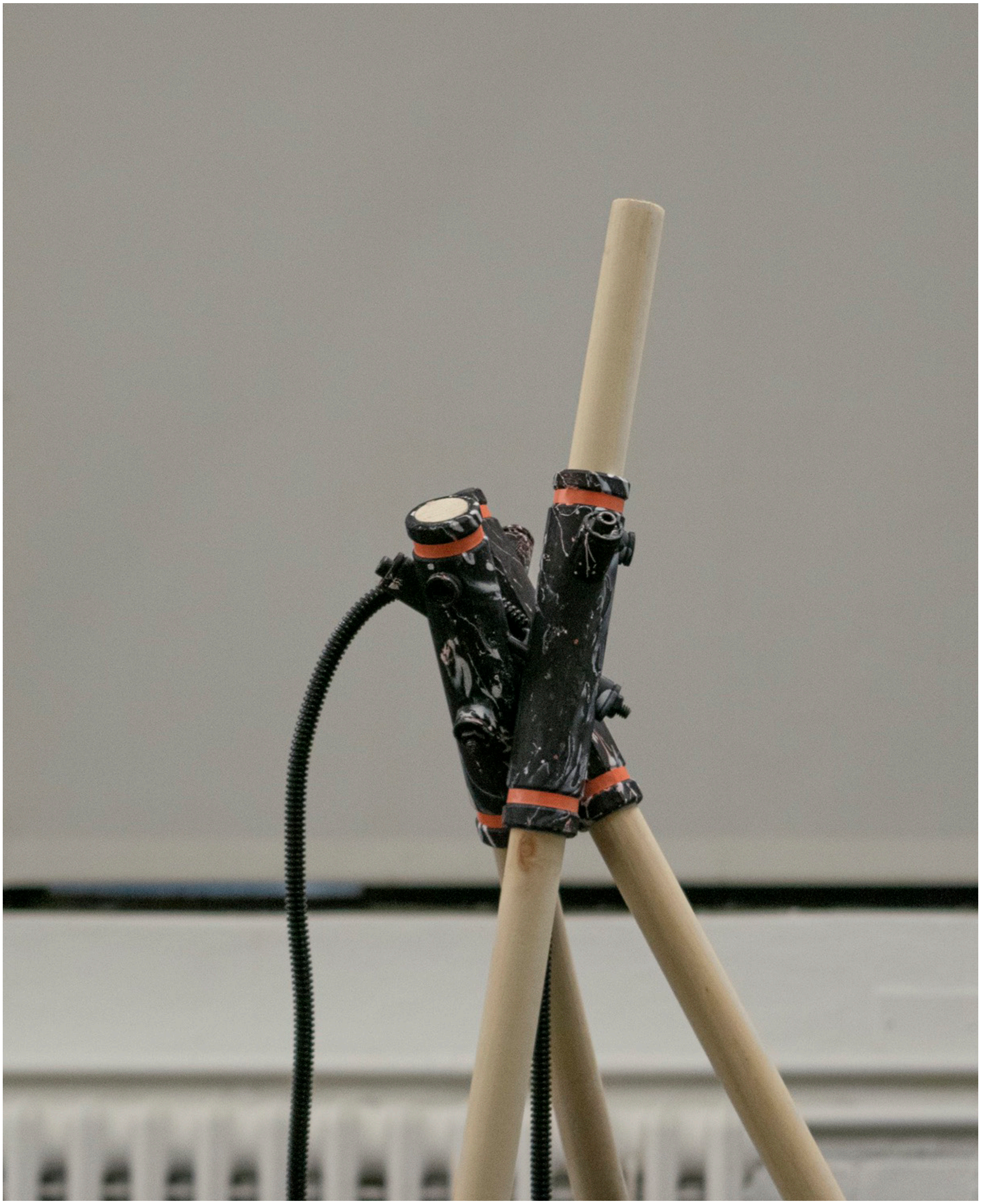
Fig. 033: Lamps, by author.

Lamps, by author.

Lamps, by author.

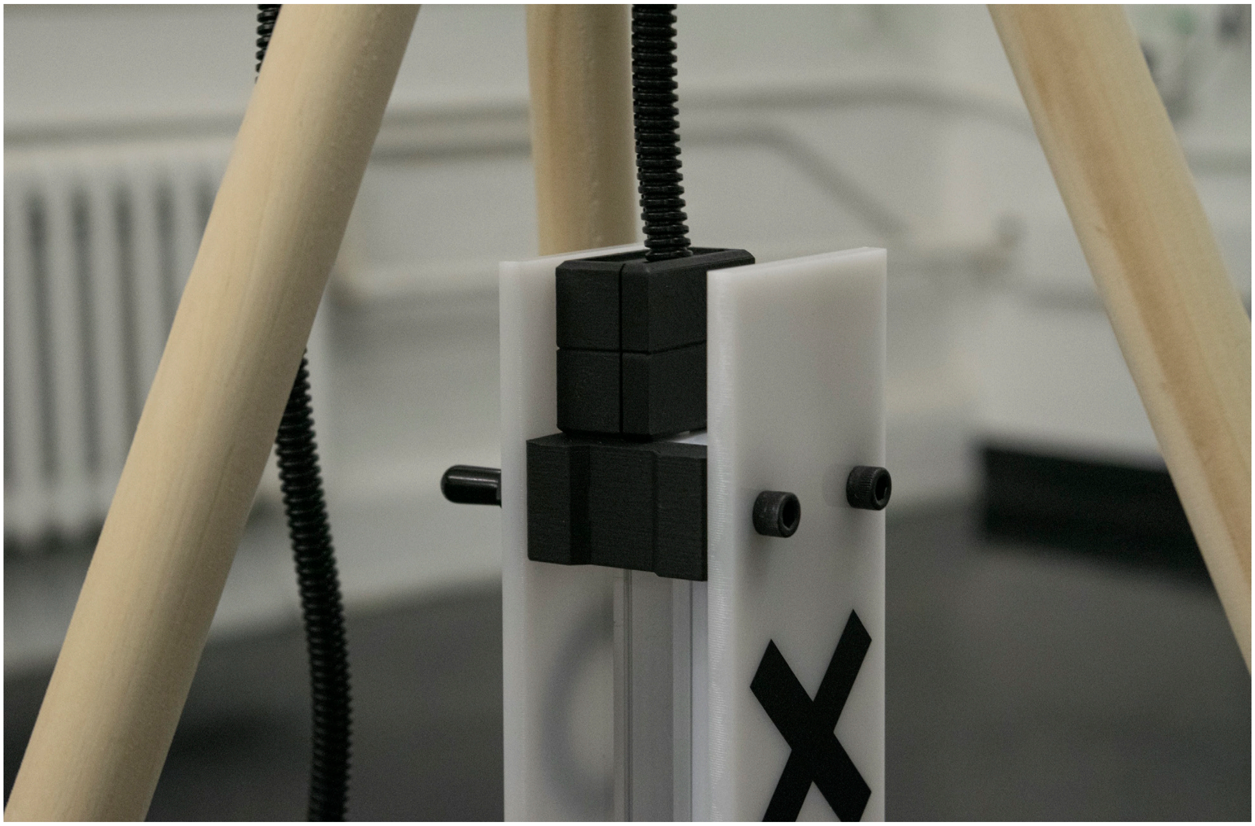


Lamps, by author.



Lamps, by author.

Lamps, by author.



Lamps, by author.

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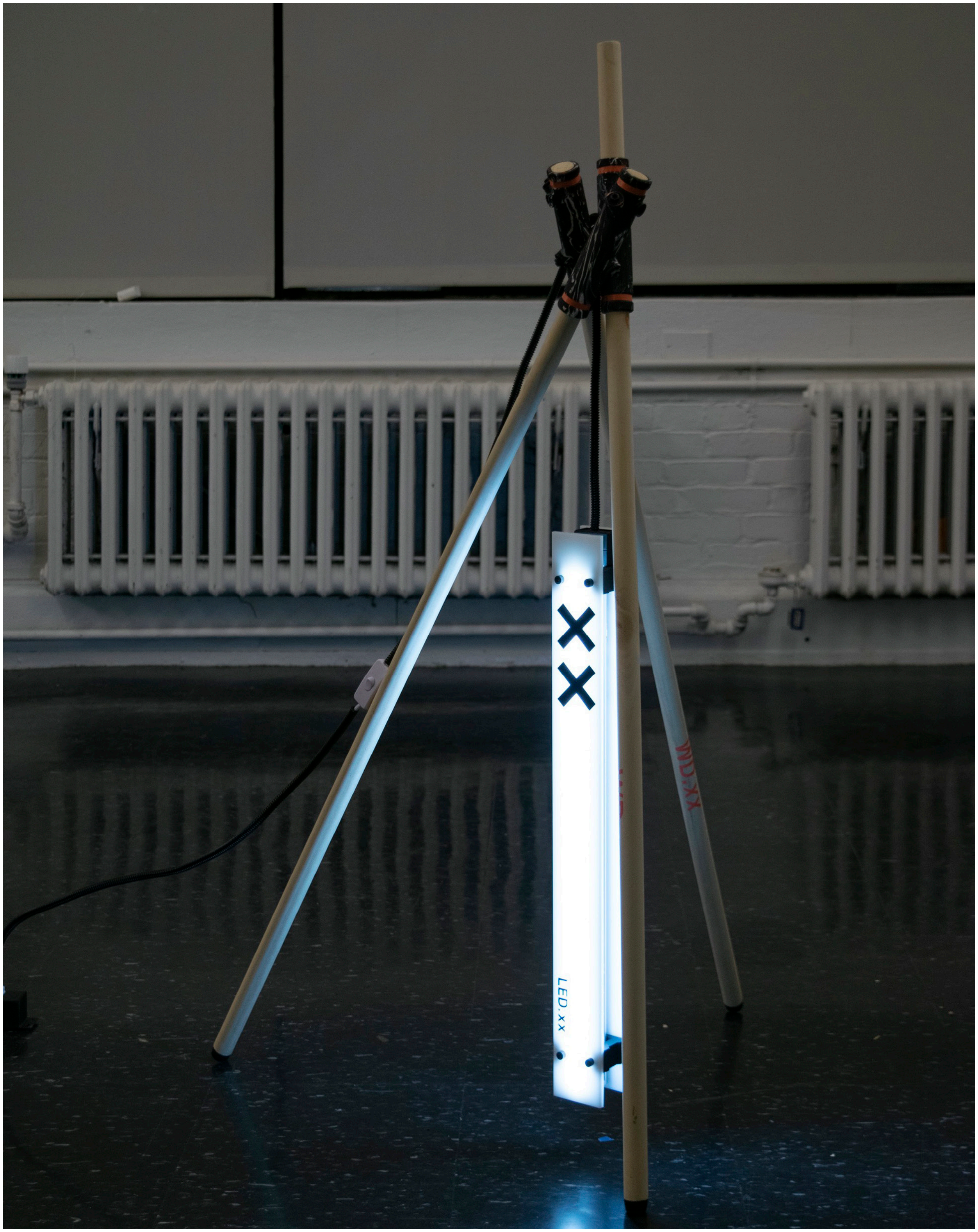
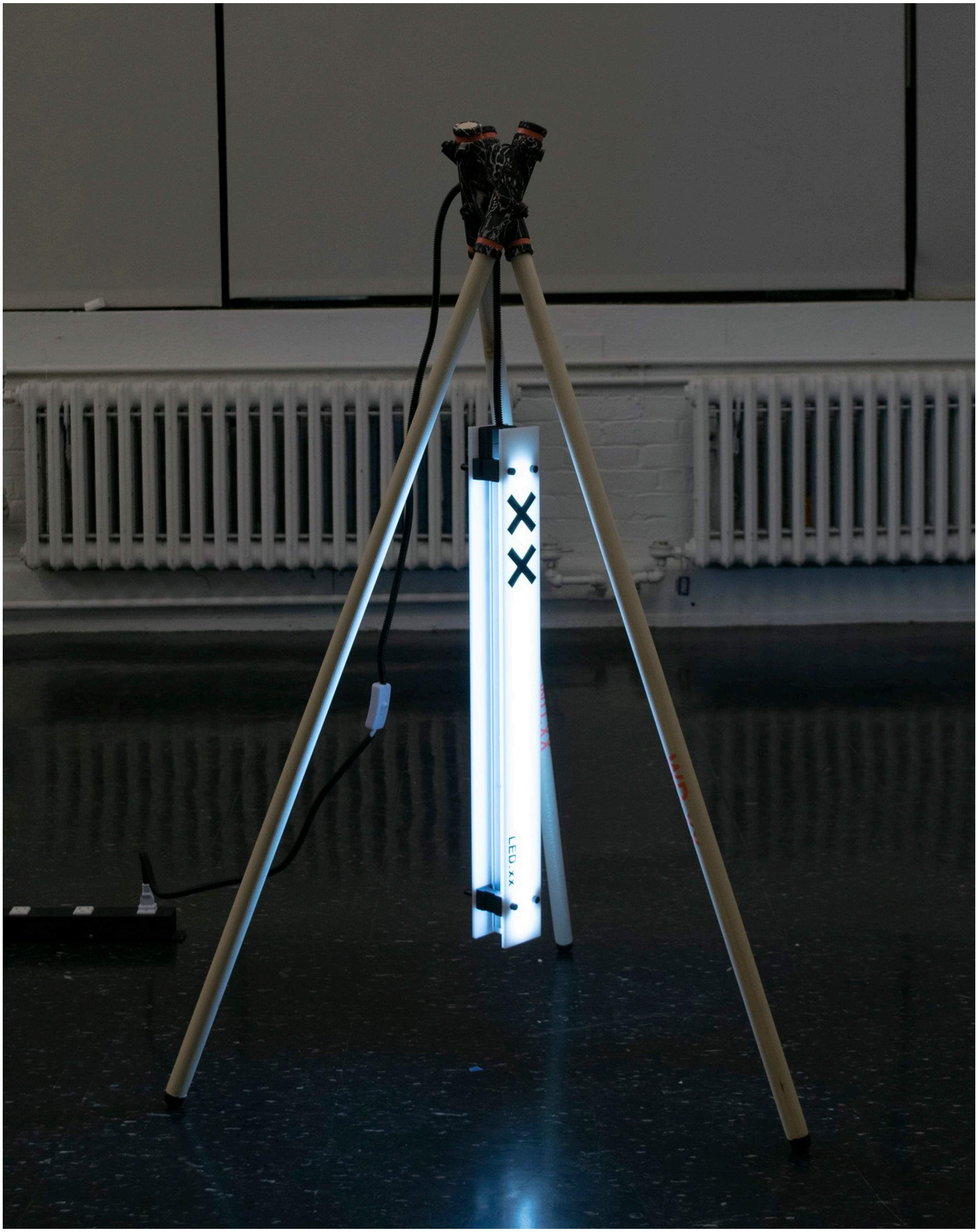


Lamps, by author.



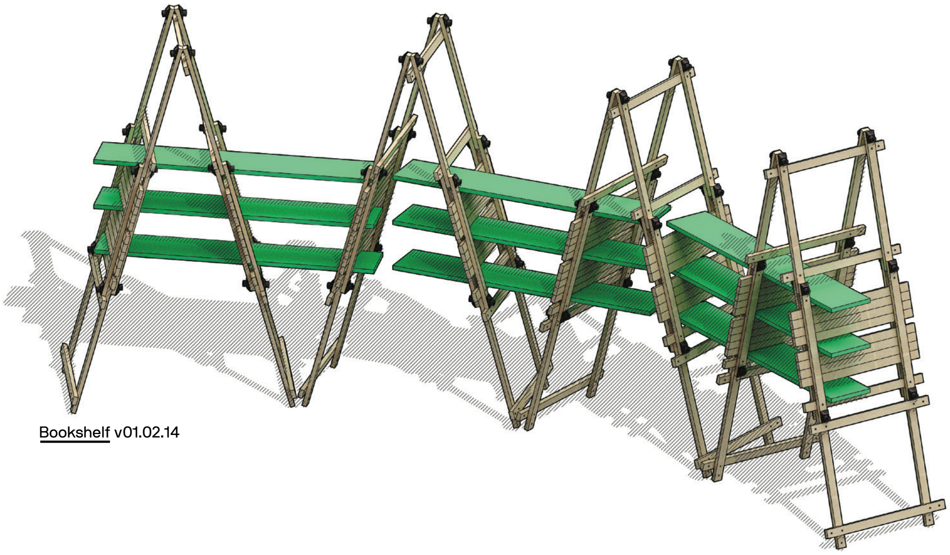
Lamps, by author.

Bookshelves

This series of bookshelves uses the smallest 1”x2” parts, combining them into longer members to produce the frames for the shelves. Common boards taken from the face of the walls become the shelves. In the case of the built example, the smaller pieces make a set of frames. Some lean on each other while another one appears to float freely. 1”x2” pieces are stacked in the frames to hold the assembly together through a friction fit. Everything can be disassembled.

Bookshelf v01.02.02

Bookshelf v01.02.10

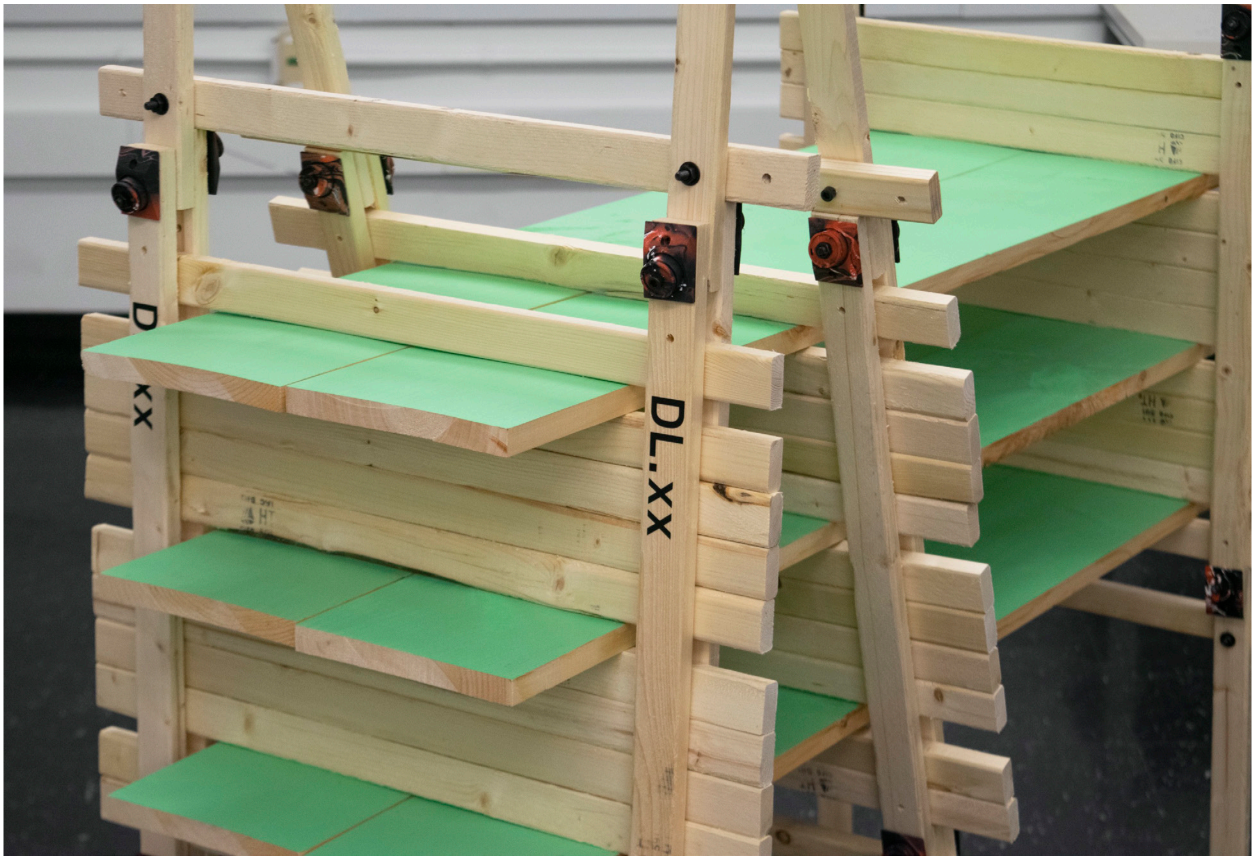


Bookshelf v01.02.14

Fig. 034: Bookshelves, by author.

Bookshelves, by author.

Bookshelves, by author.

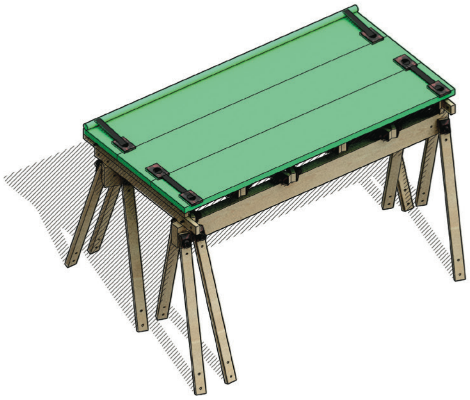


Bookshelves, by author.

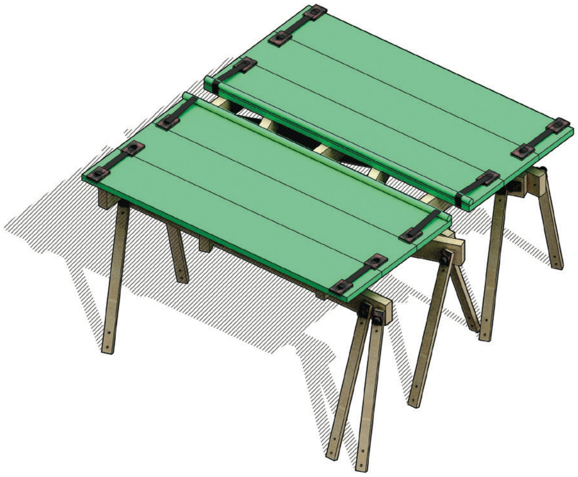
Bookshelves, by author.

Desks

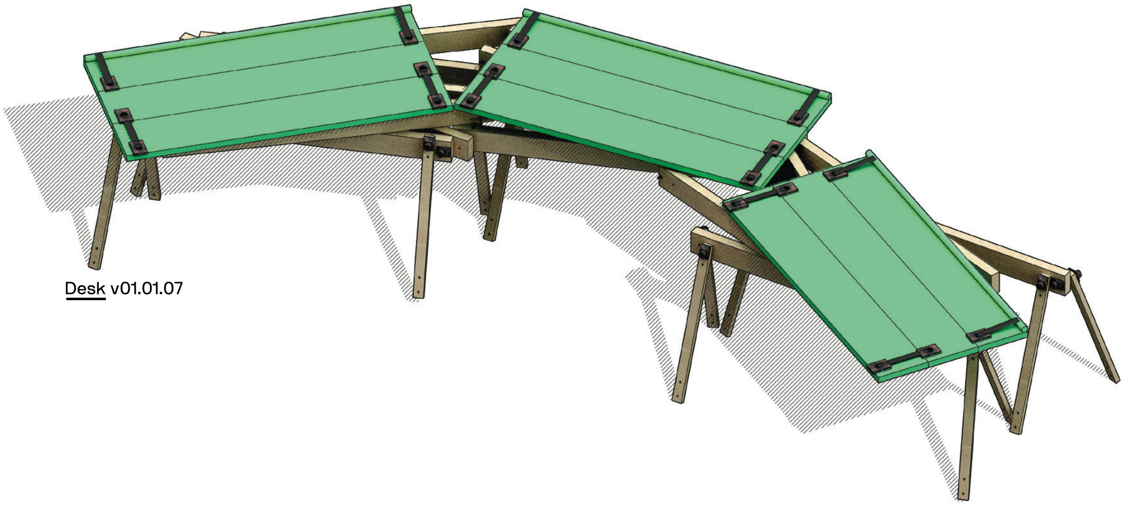
The same common boards from the walls are used to make planar surfaces, connected through ratchet straps using a part that allows for a different orientation. The smallest 1”x2” pieces are used as legs and the series can shift from a standard desk, to a double desk, to a pocket of work space for an individual or a team. In the case of the double desk, the angled parts are used on multiple different dimensions of standard material, and are rotated in different planes to create the legs, while also creating the structure for supporting the top surface of the desk. Everything can be disassembled.



Desk v01.01.02



Desk v01.01.05



Desk v01.01.07

Fig. 035: Desks, by author.

Desks, by author.

Desks, by author.

Desks, by author.

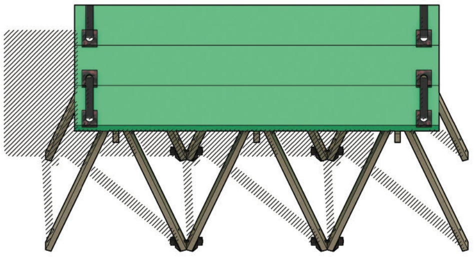
Desks, by author.

Desks, by author.

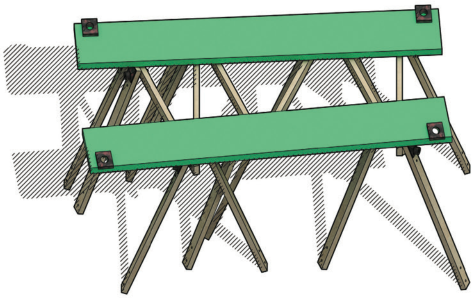
Desks, by author.

Benches

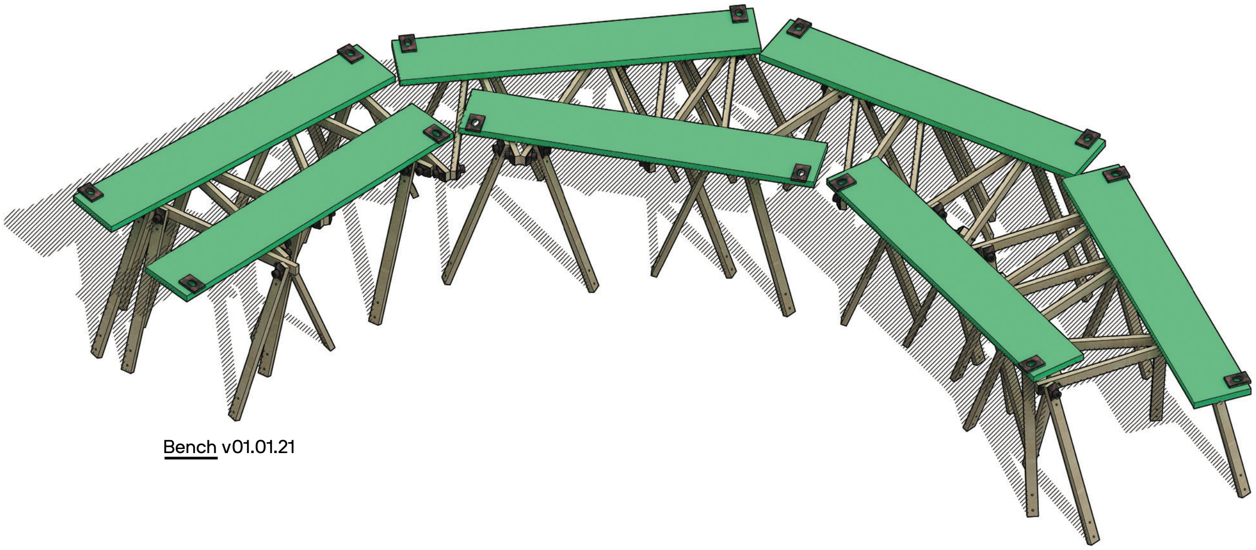
The 1”x2” pieces here are used as both the legs and the structure for the sitting surfaces. Similarly, the angled parts work in different planes, and the designer is granted a range of freedom in how the parts are assembled. The common boards are used for the bench top surfaces. Everything can be disassembled.



Bench v01.01.03

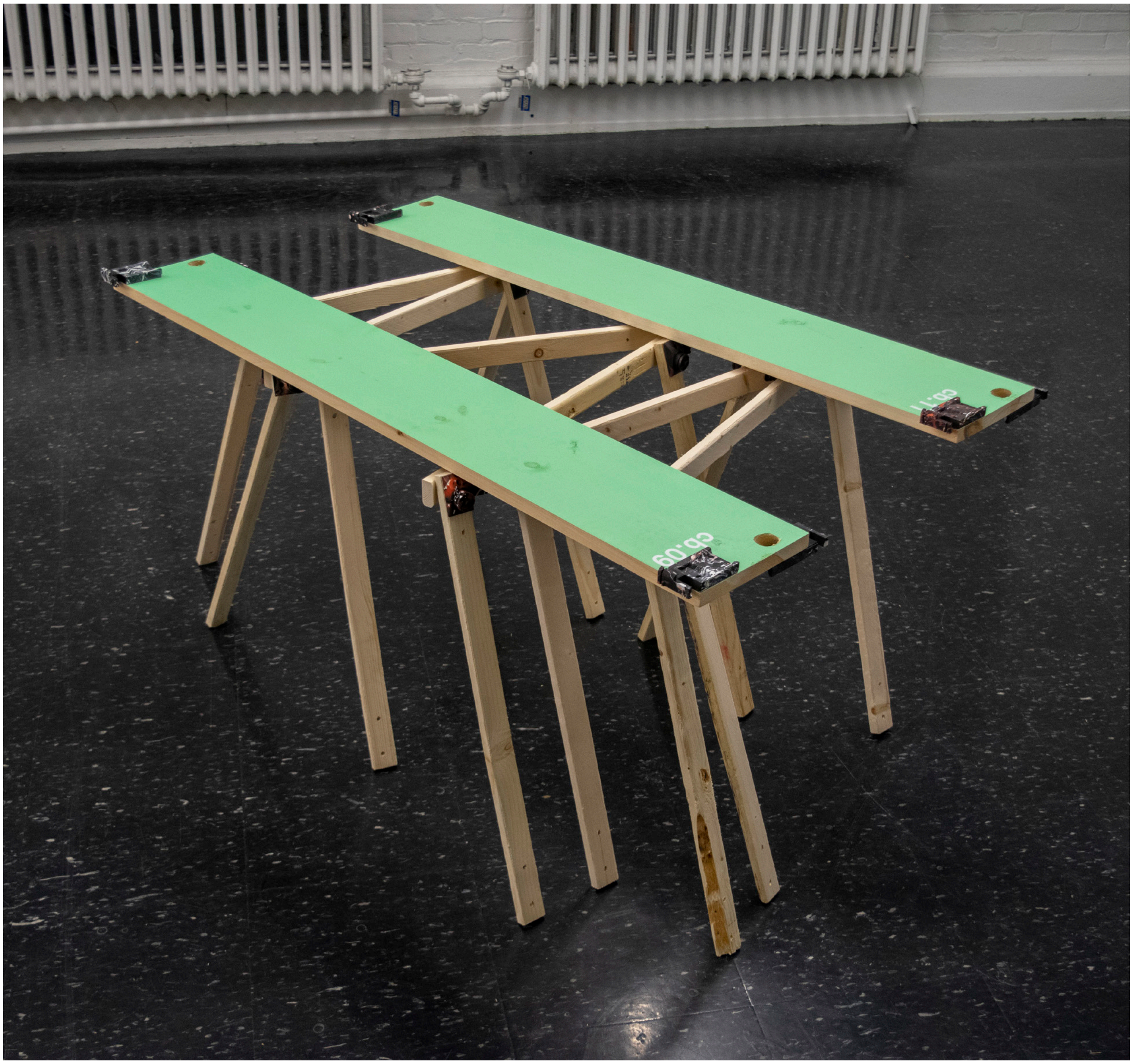


Bench v01.01.12



Bench v01.01.21

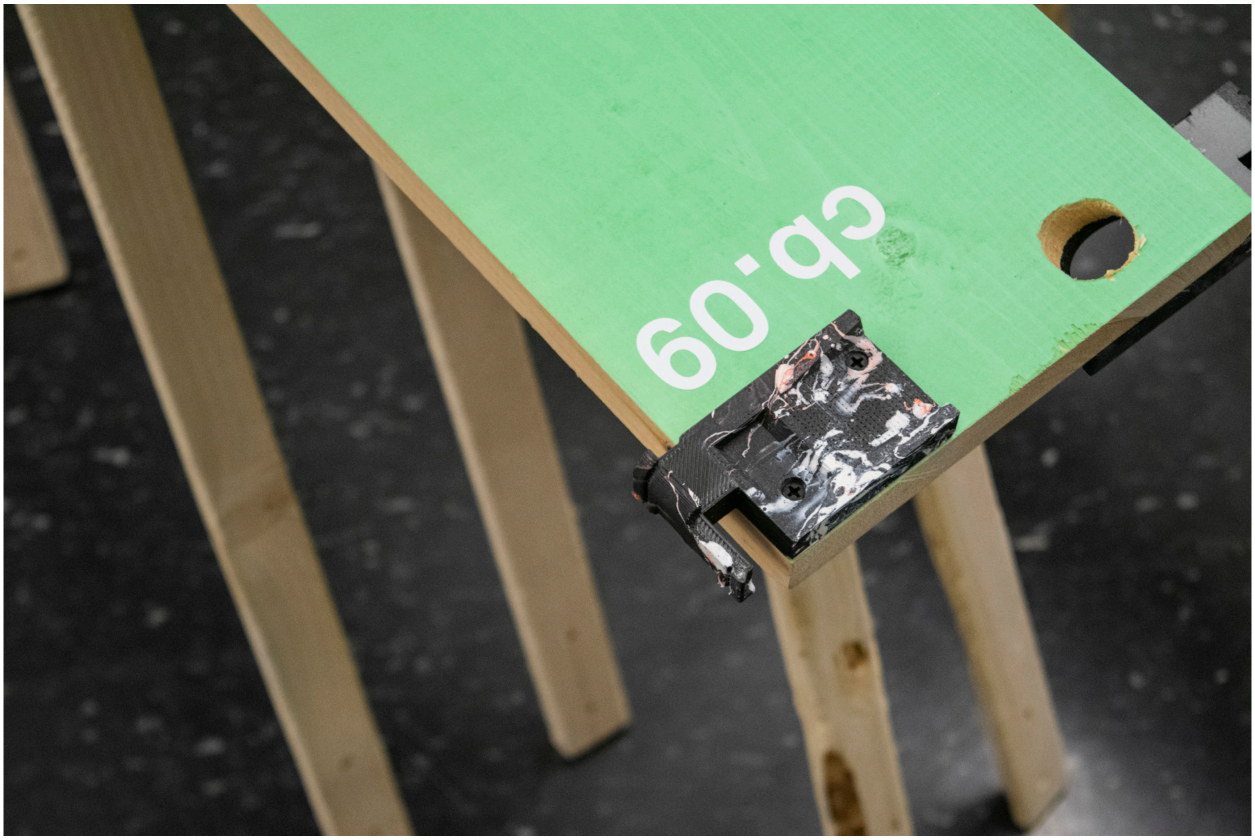
Fig. 036: Benches, by author.



Benches, by author.

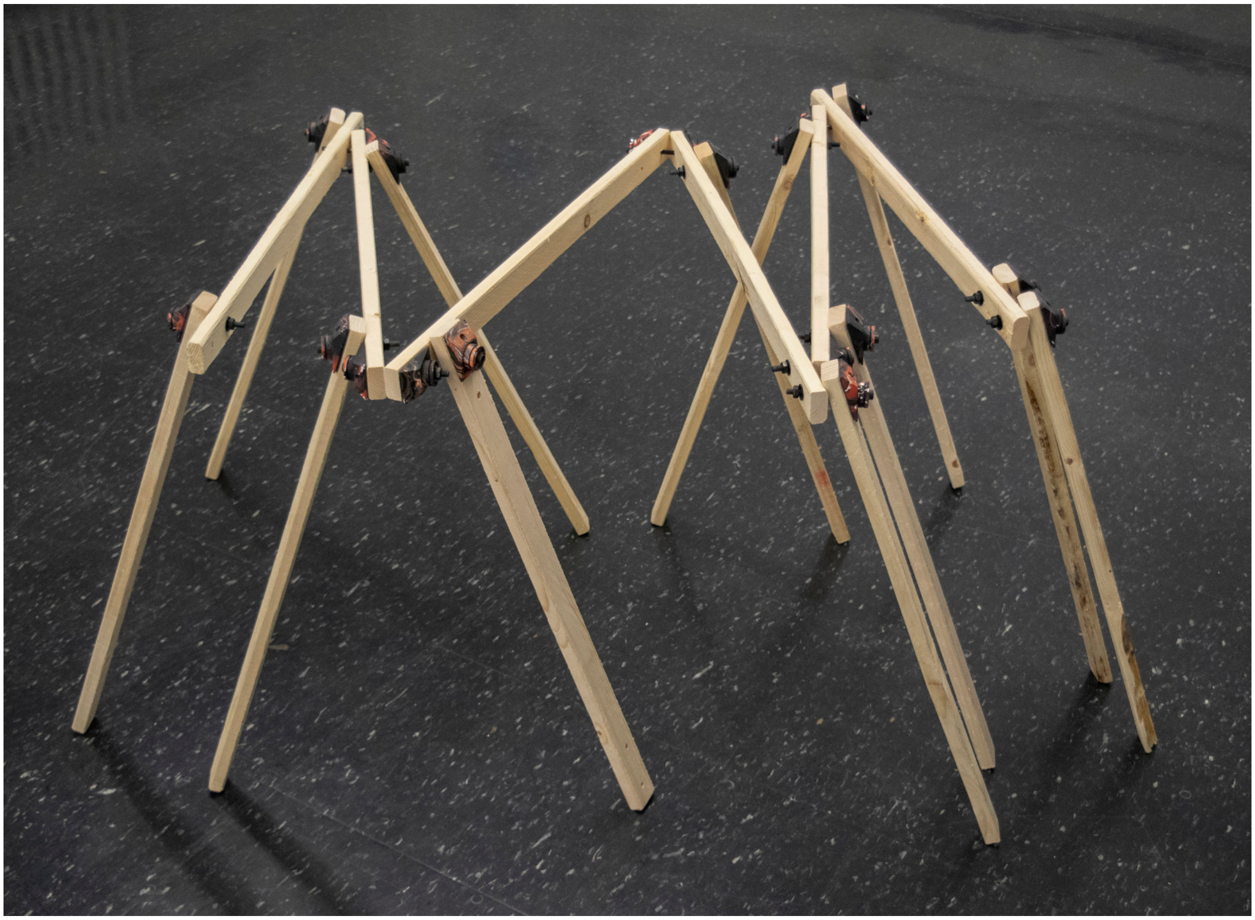
Benches, by author.

Benches, by author.



Benches, by author.

Benches, by author.



Benches, by author.

Fig. 037: QR Code for Assembly Video - https://vimeo.com/711449871, by author.

PART VIII

Implications

PART VIII
Implications

While these fabricated prototypes are made at a small to medium scale, they are designed of course with the intent that the smaller assemblies and the effects of a "calculated precarity" and a specific attitude on smaller parts could also be felt at the larger scale of an architectural layout. If it is the arrangement of smaller parts that creates differing assemblies, it is the coordination of these assemblies that then effects larger architectural effects on an interior.

Layout 1

A situation where the double desk is used to make for a standard open office environment with rows, while walls are used to create private offices amidst the rows of desks.

Layout 2

A layout that uses a variation of assemblies, where the walls become more active and liberate spaces from a strictly regulated plan, while containing flexible, active furniture in smaller pockets of space.

Layout 3

An imagined layout towards the end of the abnormal spectrum for the most freely combined assemblies. Furniture is free flowing and an active part of the plan, along with walls for the most customized or atypical arrangement of spaces. Walls and furniture greatly alter the programmatic use of a space in this layout.

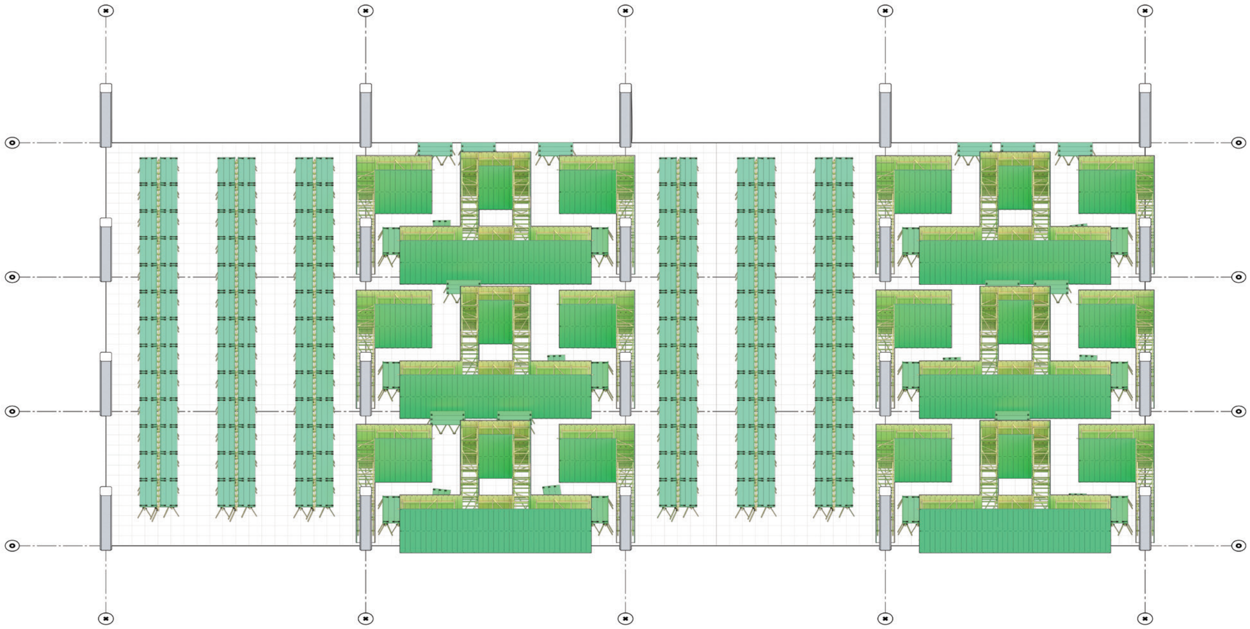


Fig. 038: Layout 1, by author.

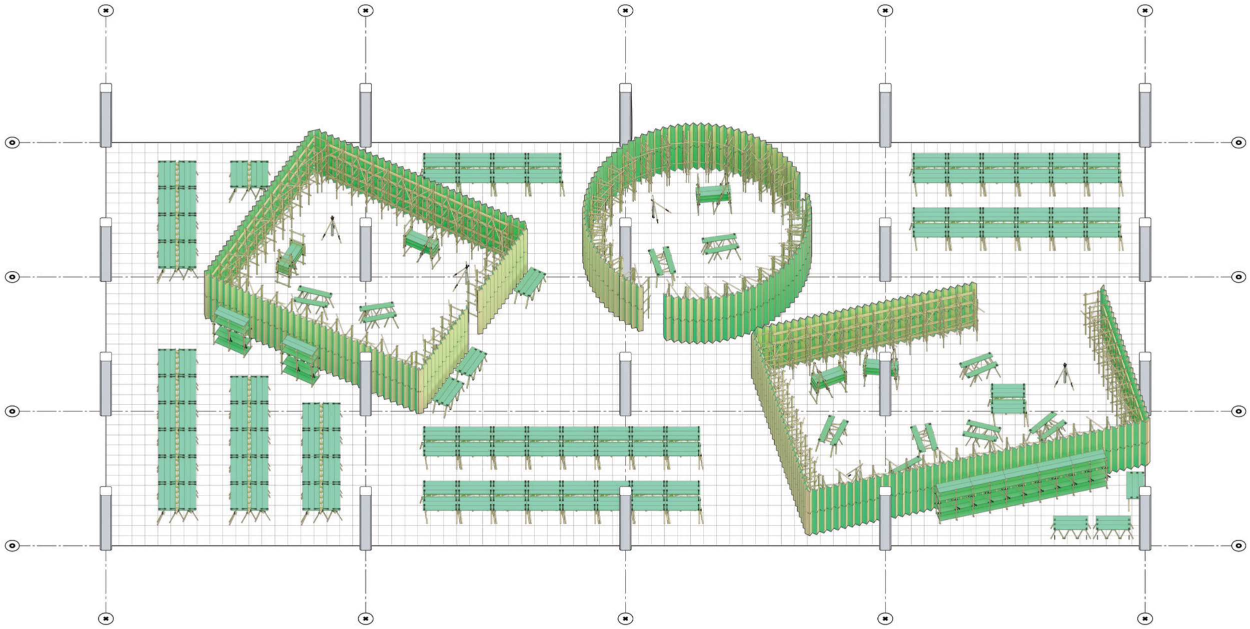


Fig. 039: Layout 2, by author.

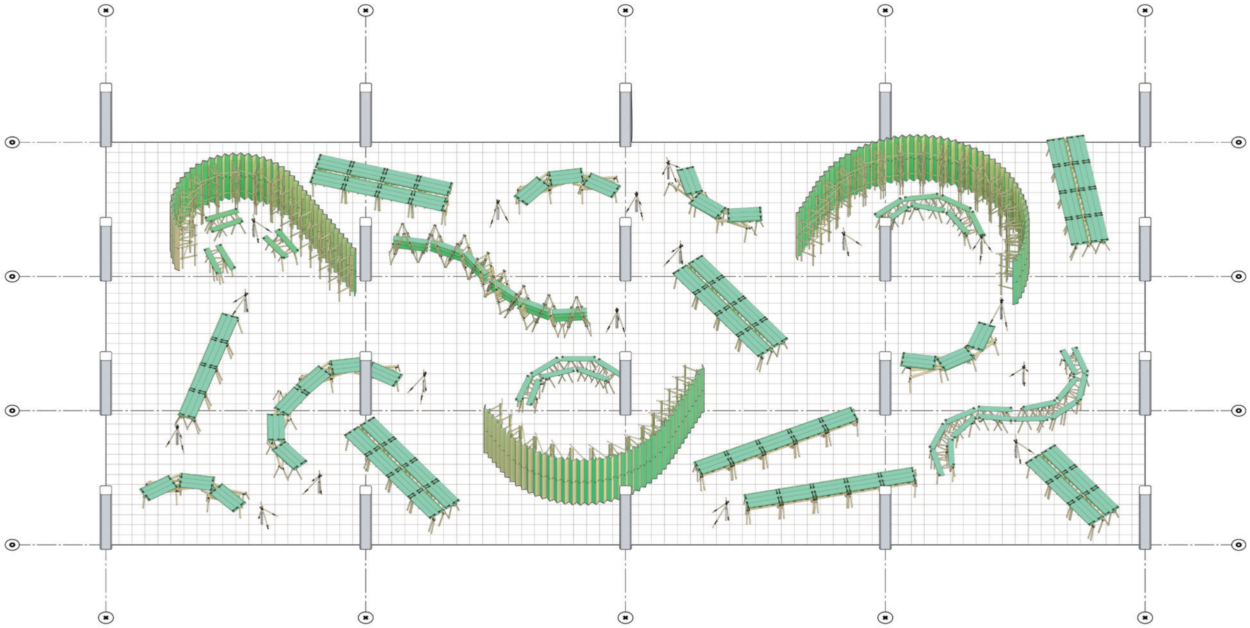


Fig. 040: Layout 3, by author.

PART IX

Conclusions

PART IX
Conclusions

While the prototypes produced through the course of this project were at a 1-to-1 scale, even larger parts would be one of the ambitions of continuing *Parts-In-Progress*. Testing on the smaller and more temporary elements of architecture was just a way to begin *Parts-In-Progress*. Even if this testing continues at the scale of furniture and partitions, this does not change the fact that larger elements such as structure and enclosure can still benefit from a *Parts-In-Progress* methodology.

These issues of scale also provoke the question of using different stock materials. Standard lumber made sense for this initial fabrication project due to the material's relative affordability and forgiveness with different fabrication techniques. While *Parts-In-Progress* does argue that even dimensional lumber is a valuable, reusable material, it is true that there is much more to study in terms of what other building materials might be appropriate for this methodology. The questions of material life cycle, or more calculated investments in material's embodied carbon would be worthwhile. Not only this, but other materials would open a series of experiments in multi-material assemblies where materials like lumber, steel, and aluminum could all have their respective advantages in an assembly.

As an initial attempt at a project that begins with a conceptual base and leads to fabricated prototypes, *Parts-In-Progress* is also meant to be a testament to the design and fabrication of the smallest pieces impacting the largest ones. This work was all produced with a limited set of small-scale tools. In an unintended proof of concept, all these assemblies were disassembled, moved from one side of the MIT campus to another, and reassembled in a short period of time. While the project is currently limited to a set of somewhat specific prototypes in an envisioned hypothetical scenario, the life of *Parts-In-Progress* has only just begun, as the methodology can be applied to different scales and different programs as a continued work-in-progress.

Fig. 041: Parts-In-Progress, by author.

Fig. 042: Rod Part, by author.

Fig. 043: Final Review, by author.

Fig. 044: Final Review, by author.

Fig. 045: Final Review, by author.

Fig. 046: Final Review, by author.

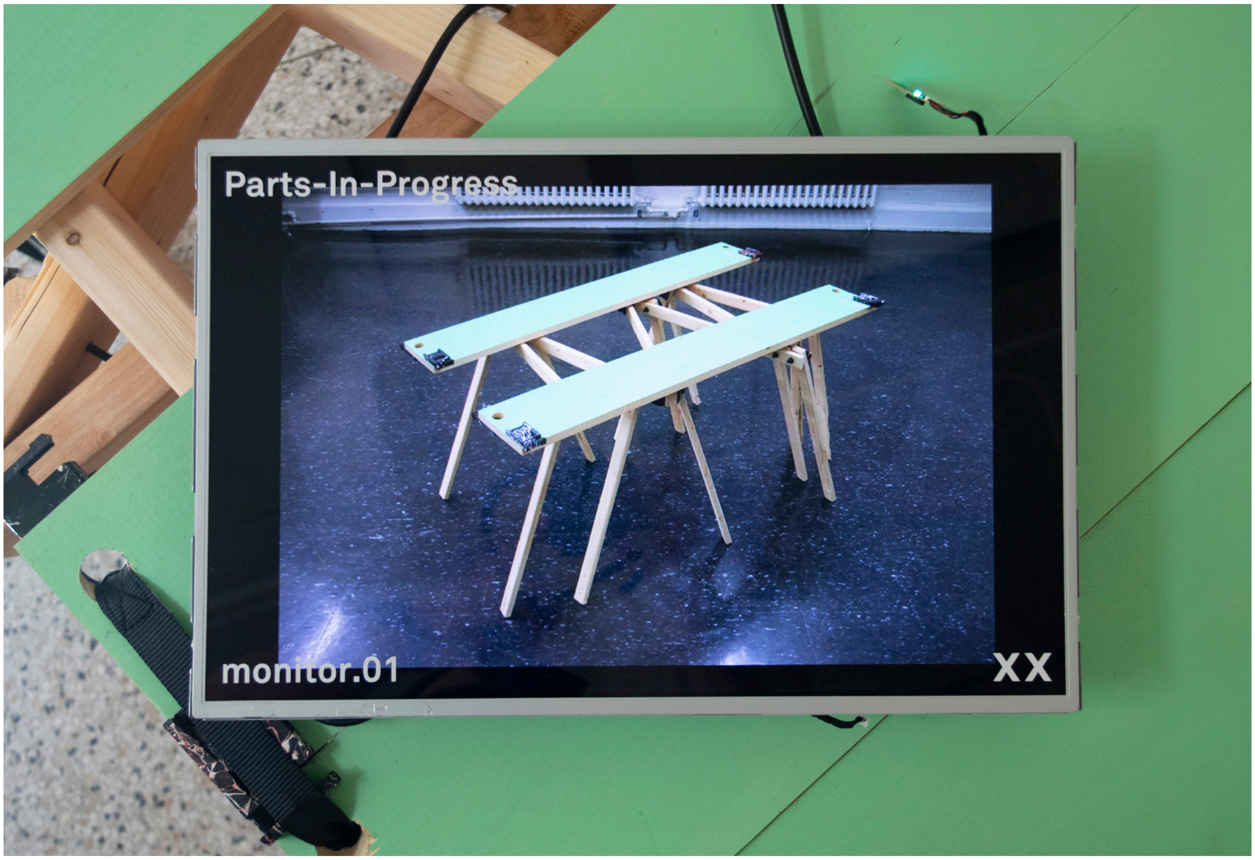


Fig. 047: Final Review, by author.

PART X

References

Notes

1. "Sustainable Management of Construction and Demolition Materials." US EPA, OLEM. Overviews and Factsheets, March 8, 2016. https://www.epa.gov/smm/sustainable-management-construction-and-demolition-materials.

2. "Why The Building Sector? – Architecture 2030." Accessed May 3, 2022. https://architecture2030.org/why-the-building-sector/.

3. United Nations, Department of Economic and Social Affairs, Population Division (2015). *World Population Prospects: The 2015 Revision, Key Findings and Advance Tables*. Working Paper No. ESA/P/WP.241.

4. Smith, Sean. "The World Needs to Build More than Two Billion New Homes over the next 80 Years." The Conversation. Accessed May 3, 2022. http://theconversation.com/the-world-needs-to-build-more-than-two-billion-new-homes-over-the-next-80-years-91794.

5. "Best Practices for Reducing, Reusing, and Recycling Construction and Demolition Materials," March 10, 2016. https://www.epa.gov/smm/best-practices-reducing-reusing-and-recycling-construction-and-demolition-materials.

6. Paruszkiewicz, Mike, Jenny H Liu, Rebecca Hanes, Eric Hoffman, Peter Hulseman, and Emma Willingham. "The Economics of Residential Building Deconstruction in Portland, OR," n.d., 28.

7. "What Is Design for Disassembly? - News - Cradle to Cradle Products Innovation Institute." Accessed May 3, 2022. https://www.c2ccertified.org/news/article/what-is-design-for-disassembly.

8. "Best Practices for Reducing, Reusing, and Recycling Construction and Demolition Materials," March 10, 2016. https://www.epa.gov/smm/best-practices-reducing-reusing-and-recycling-construction-and-demolition-materials.

9. Schmandt-Besserat, Denise. "The Earliest Uses of Clay in Syria." *Expedition Magazine - Penn Museum*, Spring 1977: 35.

10. Imperiale, Alicia. "An American Wartime Dream: The Packaged House System of Konrad Wachsmann and Walter Gropius," n.d., 5.

11. Imperiale, Alicia. "An American Wartime Dream: The Packaged House System of Konrad Wachsmann and Walter Gropius," n.d., 5.

12. Imperiale, Alicia. “An American Wartime Dream: The Packaged House System of Konrad Wachsmann and Walter Gropius,” n.d., 5.

13. “Konrad Wachsmann | American Architect | Britannica.” Accessed May 18, 2022. https://www.britannica.com/biography/Konrad-Wachsmann.

14. Museum of Modern Art, New York. “Museum of Modern Art Shows Revolutionary New Type of Steel Construction,” March 5, 1946. https://assets.moma.org/documents/moma_press-release_325504.pdf?_ga=2.269062898.227323733.1651669463-1635057236.1649725323.

15. Museum of Modern Art, New York. “Museum of Modern Art Shows Revolutionary New Type of Steel Construction,” March 5, 1946. https://assets.moma.org/documents/moma_press-release_325504.pdf?_ga=2.269062898.227323733.1651669463-1635057236.1649725323.

16. Gershenfeld, Neil. “How to Make Almost Anything” 91, no. 6 (n.d.): 16.

17. Gershenfeld, Neil. “How to Make Almost Anything” 91, no. 6 (n.d.): 16.

18. Weber, Steve. *The Success of Open Source,* 1. Cambridge, MA: Harvard University Press, 2004.

19. Fok, Wendy W., and Antoine Picon, eds. *Digital Property: Open-Source Architecture*. Architectural Design, 7. Profile, no 243. London: John Wiley & Sons, 2016.

20. See “How to Make Something That Makes (Almost) Anything” class website from 2021 for more information: https://fab.cba.mit.edu/classes/865.21/index.html.

21. Karsan, Zain. *TinyZ*. MIT Architecture. 2021.

22. Aljomairi, Maryam, and Kimball Kaiser. *DTS Printer*. MIT Architecture, 2021.

23. Weber, Steve. *The Success of Open Source,* 64. Cambridge, MA: Harvard University Press, 2004.

24. Kaiser, Kimball, and Dirk Kaiser. *Mk01* (version 01.01.04), 2021.

25. QMK Firmware. "QMK Firmware - An Open Source Firmware for AVR and ARM Based Keyboards." Accessed May 4, 2022. https://qmk.fm/.

26. Parvin, Alastair. "Architecture (and the Other 99%): Open-Source Architecture and Design Commons." *Architectural Design* 83, no. 6 (November 2013): 90. https://doi.org/10.1002/ad.1680.

27. Parvin, Alastair. "Architecture (and the Other 99%): Open-Source Architecture and Design Commons." *Architectural Design* 83, no. 6 (November 2013): 94. https://doi.org/10.1002/ad.1680.

28. Parvin, Alastair. "Architecture (and the Other 99%): Open-Source Architecture and Design Commons." *Architectural Design* 83, no. 6 (November 2013): 93. https://doi.org/10.1002/ad.1680.

29. Bergdoll, Barry., Peter Christensen, and Ron. Broadhurst. Home Delivery : Fabricating the Modern Dwelling. New York: Museum of Modern Art, 2008.

30. Sanchez, Jose. *Architecture for the Commons,* 63-64. New York: Routledge, 2020.

31. See LEGO website for more information: https://www.lego.com/en-us.

32. Retsin, Gilles. "Discrete Architecture in the Age of Automation." *Architectural Design* 89, no. 2 (March 2019): 6–13. https://doi.org/10.1002/ad.2406.

33. Carpo, Mario. *The Alphabet and the Algorithm,* 41. Cambridge, Mass: MIT Press, 2011.

34. Sanchez, Jose. *Architecture for the Commons,* 60. New York: Routledge, 2020.

35. Sanchez, Jose. "Architecture for the Commons: Participatory Systems in the Age of Platforms." *Architectural Design* 89, no. 2 (March 2019): 27. https://doi.org/10.1002/ad.2408

36. Certain Measures. “Mine the Scrap.” Accessed May 18, 2022. https://certainmeasures.com/MINE-THE-SCRAP.

37. “Someparts.Parts.” Accessed May 18, 2022. https://someparts.parts/.

38. HANNAH. “Knot.” Accessed May 18, 2022. https://www.hannah-office.org/work/knot.

39. “Creative Building Toys for Kids | K’NEX | Basic Fun!” Accessed May 18, 2022. https://www.basicfun.com/knex/index.html?pc.

40. Brand, Stewart. How Buildings Learn: What Happens After They’re Built. New York, NY: Viking, 1994.

Bibliography

Aljomairi, Maryam, and Kimball Kaiser. *DTS Printer*. MIT Architecture, 2021.

"Best Practices for Reducing, Reusing, and Recycling Construction and Demolition Materials," March 10, 2016. https://www.epa.gov/smm/best-practices-reducing-reusing-and-recycling-construction-and-demolition-materials.

Brand, Stewart. How Buildings Learn: What Happens After They're Built. New York, NY: Viking, 1994.

Carpo, Mario. *The Alphabet and the Algorithm*. Cambridge, Mass: MIT Press, 2011.

Certain Measures. "Mine the Scrap." Accessed May 18, 2022. https://certainmeasures.com/MINE-THE-SCRAP.

"Creative Building Toys for Kids | K'NEX | Basic Fun!" Accessed May 18, 2022. https://www.basicfun.com/knex/index.html?pc.

Fok, Wendy W., and Antoine Picon, eds. *Digital Property: Open-Source Architecture*. Architectural Design. Profile, no 243. London: John Wiley & Sons, 2016.

Gershenfeld, Neil. "How to Make Almost Anything" 91, no. 6 (n.d.): 16.

Imperiale, Alicia. "An American Wartime Dream: The Packaged House System of Konrad Wachsmann and Walter Gropius," n.d., 5.

Kaiser, Kimball, and Dirk Kaiser. *Mk01* (version 01.01.04), 2021.

Karsan, Zain. *TinyZ*. MIT Architecture, 2021.

HANNAH. "Knot." Accessed May 18, 2022. https://www.hannah-office.org/work/knot.

"Konrad Wachsmann | American Architect | Britannica." Accessed May 18, 2022. https://www.britannica.com/biography/Konrad-Wachsmann.

Museum of Modern Art, New York. "Museum of Modern Art Shows Revolutionary New Type of Steel Construction," March 5, 1946. https://assets.moma.org/documents/moma_press-release_325504.pdf?_ga=2.269062898.227323733.1651669463-1635057236.1649725323.

Paruszkiewicz, Mike, Jenny H Liu, Rebecca Hanes, Eric Hoffman, Peter Hulseman, and Emma Willingham. "The Economics of Residential Building Deconstruction in Portland, OR," n.d., 28.

Parvin, Alastair. "Architecture (and the Other 99%): Open-Source Architecture and Design Commons." *Architectural Design* 83, no. 6 (November 2013): 90–95. https://doi.org/10.1002/ad.1680.

QMK Firmware. "QMK Firmware - An Open Source Firmware for AVR and ARM Based Keyboards." Accessed May 4, 2022. https://qmk.fm/.

Retsin, Gilles. "Discrete Architecture in the Age of Automation." *Architectural Design* 89, no. 2 (March 2019): 6–13. https://doi.org/10.1002/ad.2406.

Sanchez, Jose. *Architecture for the Commons*. New York: Routledge, 2020.

———. "Architecture for the Commons: Participatory Systems in the Age of Platforms." *Architectural Design* 89, no. 2 (March 2019): 22–29. https://doi.org/10.1002/ad.2408.

Schmandt-Besserat, Denise. "The Earliest Uses of Clay in Syria." *Expedition Magazine - Penn Museum*, Spring 1977. https://www.penn.museum/sites/expedition/the-earliest-uses-of-clay-in-syria/.

Smith, Sean. "The World Needs to Build More than Two Billion New Homes over the next 80 Years." The Conversation. Accessed May 3, 2022. http://theconversation.com/the-world-needs-to-build-more-than-two-billion-new-homes-over-the-next-80-years-91794.

"Someparts.Parts." Accessed May 18, 2022. https://someparts.parts/.

US EPA, OLEM. "Sustainable Management of Construction and Demolition Materials." Overviews and Factsheets, March 8, 2016. https://www.epa.gov/smm/sustainable-management-construction-and-demolition-materials.

Weber, Steve. *The Success of Open Source*. Cambridge, MA: Harvard University Press, 2004.

"What Is Design for Disassembly? - News - Cradle to Cradle Products Innovation Institute." Accessed May 3, 2022. https://www.c2ccertified.org/news/article/what-is-design-for-disassembly.

"Why The Building Sector? – Architecture 2030." Accessed May 3, 2022. https://architecture2030.org/why-the-building-sector/.

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Fig. 001: B.O.B., Jonathan Chavez, Adam Shilling, Kimball Kaiser.

Fig. 002: B.O.B., Jonathan Chavez, Adam Shilling, Kimball Kaiser.

Fig. 003: Konrad Wachsmann, Packaged House Connections. https://www.researchgate.net/figure/Konrad-Wachsmann-and-Walter-Gropius-Frame-connection-of-the-Packaged-House-System_fig16_339948319.

Fig. 004: Konrad Wachsmann, Packaged House System. https://www.atlasofplaces.com/architecture/usaf-aircraft-hangar/.

Fig. 005: Konrad Wachsmann, Steel Frame Joint. https://www.atlasofplaces.com/architecture/usaf-aircraft-hangar/.

Fig. 006: Konrad Wachsmann, Aircraft Hangar. https://www.atlasofplaces.com/architecture/usaf-aircraft-hangar/.

Fig. 007: DTS Printer, Maryam Aljomairi and Kimball Kaiser.

Fig. 008: DTS Printer, Maryam Aljomairi and Kimball Kaiser.

Fig. 009: mk01, Kimball Kaiser and Dirk Kaiser.

Fig. 010: mk01, Kimball Kaiser and Dirk Kaiser.

Fig. 011: mk01, Kimball Kaiser and Dirk Kaiser.

Fig. 012: mk01, Kimball Kaiser and Dirk Kaiser.

Fig. 013: Wikihouse. https://www.researchgate.net/figure/The-WikiHouse-building-parts-Wikiparts-Source-WikiHousecc_fig1_335507479

Fig. 014: Diagram for the differences between holistic and non-holistic sets,

Jose Sanchez. “Architecture for the Commons.” 2020.

Fig. 015: Tallinn Architecture Biennale Pavilion, Gilles Retsin. https://www.retsin.org/Tallinn-Architecture-Biennale-Pavilion.

Fig. 016: Tallinn Architecture Biennale Pavilion, Gilles Retsin. https://www.retsin.org/Tallinn-Architecture-Biennale-Pavilion.

Fig. 017: Mine the Scrap, Certain Measures. https://certainmeasures.com/MTS_003.

Fig. 018: Someparts, Stock-a-Studio. https://stockastudio.com/

Fig. 019: Axis of Considered Material Usage, by author.

Fig. 020: Axis of 3D Composition and Assem, by author.

Fig. 021: Log Knot, HANNAH. https://www.hannah-office.org/work/knot.

Fig. 022: Open Air Theatre, Colab-19. Photography by Alberto Roa. https://www.dezeen.com/2021/01/19/la-concordia-amphitheatre-colab-19-bogota-architecture/

Fig. 023: Parts-In-Progress “conceptual zone,” by author.

Fig. 024: (Left) Diagram by Jose Sanchez, (Right) Diagram by author.

Fig. 025: Parts-In-Progress, by author.

Fig. 026: Adaptable Parts-In-Progress, by author.

Fig. 027: Manipulations at Ends of Members, by author.

Fig. 028: Appropriate Layers, by author.

Fig. 029: Appropriate Program, by author.

Fig. 030: Dimensional Lumber Sizes, by author.

Fig. 031: Prototypes from the Same Parts, by author.